ISSN 1392-3730/eISSN 1822-3605

JOURNAL of CIVIL ENGINEERING and MANAGEMENT

2026
Volume 32
Issue 6
Pages 834–853
https://doi.org/10.3846/jcem.2026.27815

DEVELOPMENT OF BASED ON BIM DATA EXTRACTION AND AUTOMATION EVALUATION PROCESS FOR BARRIER-FREE CERTIFICATION

Eunsang YU[1], Yonghan AHN[2], Jungsik CHOI[3]✉

[1]*Department of Smart City Engineering, Hanyang University, Ansan City, 15588, Republic of Korea*
[2]*Department of Architecture, Hanyang University, Ansan City, 15588, Republic of Korea*
[3]*Department of Urban Architecture, Kangwon National University, Samcheok City, 25913, Republic of Korea*

Article History:
- received 7 September 2025
- accepted 5 May 2026

Abstract. Population ageing and increasing diversity in building users have intensified the need for Barrier-Free (BF) certification. However, the growing complexity of buildings has made conventional two-dimensional drawing-based certification workflows inefficient due to limited spatial information and repetitive manual interpretation. This study proposes a BIM-based automated evaluation process for BF certification by structuring certification criteria into rule-based BIM data extraction and object classification logic. BF certification criteria were classified according to user characteristics, facility types, object conditions, spatial relations, and required attributes. Based on this framework, seven BIM-based evaluation methods were developed, including space search, object search, placement verification, presence checking, and attribute extraction. The proposed process was applied to a multi-story BIM model containing approximately 18,000 objects. As a result, 253 door-related objects associated with 68 spatial entities were evaluated within approximately 60 seconds, whereas equivalent manual review required approximately 7,590 seconds. These results confirm that BIM-based automation significantly improves efficiency and reduces omission risks in certification tasks, demonstrating its applicability to broader BIM-based compliance assessment.

Keywords: Building Information Modeling (BIM), design certification evaluation, barrier free, automation assessment, analysis, classifying evaluation data.

✉Corresponding author. E-mail: *jungsikchoi@kangwon.ac.kr*

1. Introduction

The significance of barrier-free (BF) certification has become increasingly important due to several global trends, including the aging population, a continuous increase in the disabled population, a rise in foreign travelers, multicultural families, and declining birth rates (Jang & Kim, 2016). Consequently, interest in BF certification, which aims to design accessible facilities for different demographic groups, is growing (Lee, 2016). In addition, the scope of BF certification is expanding to cover a broader range of building types, evaluation subjects, and assessment items (Kim & Koo, 2022). Advancements in construction technology have also led to the development of more diverse and multi-purpose buildings (Hong & Kim, 2024). As a result, the number of areas and facilities that need to be reviewed increased, which also increased the time and resources required for BF certification evaluations (Shin, 2020). Furthermore, as buildings become larger, both data management and evaluation complexity also become increasingly burdensome (Ryu et al., 2018).

If the burden of BF certification evaluation could be reduced and the review process could be conducted during the pre-certification stage, it would make highly satisfactory designs possible and minimize design changes during the construction phase. However, the current evaluation process through 2D drawings comes with two major problems: excessive data requirements and frequent design errors (Kang et al., 2022). Building Information Modeling (BIM) is one approach to integrate a range of building information, such as materials, processes, construction costs, and specifications, into 3D models, which makes it easier to produce, manage, and utilize information throughout the construction process (Yu et al., 2021). Moreover, by leveraging BIM technology, it is possible to automate BF certification evaluations by utilizing 3D data and architectural information at the design stage (Hong & Park, 2020).

According to a survey of experts, BIM-based evaluation methods were significantly more efficient than traditional 2D CAD-based methods of BF certification (Choi & Kim, 2017). Although previous BIM-based studies have demonstrated the efficiency of digital evaluation approaches, limited research has addressed how BF certification criteria can be systematically translated into rule-based BIM evaluation logic applicable to actual certification workflows. In particular, few studies have proposed a structured classification framework linking BF certification items, spatial conditions, object properties, and BIM parameter extraction within a unified evaluation process. Therefore, this study aims to develop a BIM-based automated evaluation process for BF certification by structuring certification criteria into rule-based BIM data extraction and object classification logic (Lee et al., 2012). Specifically, certification criteria were analyzed to classify required evaluation items, object categories, and BIM attributes necessary for automated rule-based assessment. In other words, the aim is to develop a methodology for evaluating BF certification using BIM data. This automated evaluation process is expected to increase the efficiency of BF certification, reduce the workload of designers and evaluators, and ultimately improve the overall quality and comprehensiveness of building designs (Khoshdelnezamiha et al., 2020).

The study aims to verify the practical feasibility of BIM-based automated BF certification and evaluate its efficiency in comparison with conventional 2D drawing-based review. It illustrates how BIM technology can streamline BF certification assessments, contribute to the wider adoption of BIM in the construction industry, and facilitate a more inclusive built environment (Ma et al., 2022).

This research employs a structured methodology to evaluate current practices and develop a BF certification automation system utilizing BIM technology. The study consists of three main stages: investigating the current status of BF certification (BF Certification System, 2020), analyzing relevant commentary, and developing an automated evaluation method based on BIM data. By surveying the current practices, we identified areas for improvement in the evaluation methodology and highlighted the benefits of implementing an automated evaluation system (Huang et al., 2022).

In the next phase, we examined BF certification commentaries and analyzed the evaluation goals, assessment methods, and calculation criteria (Dubljević et al., 2024). This analysis is essential to understand how the certification guidelines can ensure accessibility for different user groups, and it informs the planning of automated evaluations. Furthermore, we explored automated evaluation methods using BIM data and assessed the feasibility of extracting BF certification data from BIM design models. This was done to determine whether the necessary building information could be retrieved programmatically (Widell, 2013).

Finally, an automated evaluation methodology was developed and applied to the BF certification process. This method leverages BIM spatial data, object geometry, building properties, and parameter data to explore the possibilities of automating the evaluation process. Through this study, we aim to improve the BF certification process, propose an efficient evaluation methodology, and enhance the usability of BIM data for future certification tasks.

The research methodology of this study comprises six steps:

1) Status Investigation and Needs Assessment: First, the need for BF certification and its evaluation methods are investigated. Existing evaluation methodologies are reviewed to identify areas of improvement, and the potential benefits of an automated evaluation system are explored.
2) Analysis of BF Certification Manuals: BF certification manuals from several countries and regions are collected and reviewed. These documents are analyzed to extract common goals, evaluation methods, and criteria. Subsequently, key elements that can be universally applied to BF certification are summarized.
3) Analysis of BIM Data Evaluation Methodology: The study identifies appropriate calculation criteria from BF certification commentaries using data embedded within the BIM models. The study extracts relevant spatial data, object geometries, and building attributes and assesses their applicability for BF certification. Hence, this extraction process evaluates the potential for using BIM data in BF certification.
4) Development of an Automated Evaluation Process: The required data types and attributes for BF certification are identified and classified. An automated process is then developed to extract and evaluate these data from BIM models. The data for automated analysis are divided into major types, and the evaluation methods are categorized according to established standards.
5) Application and Testing of Automated Evaluation Methodology: The developed automatic evaluation process is then applied to BIM design-file samples. A partially automated BF certification evaluation is conducted to validate both the efficiency and accuracy of the evaluation using BIM-based data.
6) Verification and Analysis: The automated evaluation system is verified by comparing the results with existing 2D CAD-based evaluation methods. The efficiency, accuracy, and completeness of the BIM-based automatic evaluation are then analyzed and compared to conventional methods.

By following this approach, the study aims to demonstrate the feasibility and advantages of BIM technology in facilitating automated BF certification assessments. The expected outcomes of the study could significantly enhance the work efficiency of both designers and evaluators while simultaneously improving the overall quality and accessibility of building designs.

Generally, research on BIM-based automation focuses on several key areas. During the development of an automated evaluation process, efforts are being made to create processes and algorithms that can automatically evaluate complex design criteria, such as accessibility standards, environmental performance, and structural safety. More specifically, this automated evaluation methodology allows BIM models to be evaluated automatically, which reduces assessment time and ensures consistency across multiple assessments (Choi & Kim, 2014).

Integration with Regulatory Standards: Efforts are being made to integrate BIM automation tools with regulatory standards, such as building codes, energy performance benchmarks, and safety regulations (Maqsoom et al., 2025). Through this integration, automated assessments can comply with applicable laws and industry standards (Kim & Choi, 2016).

Data Interoperability and Standardization: Research is focused on improving the interoperability and standardization of BIM data to enable efficient automation (Song, 2014). This allows BIM models to be applied universally across a wide range of evaluation tools and platforms, which enables easier sharing and evaluation across various projects and stakeholders (Kim et al., 2013b).

Recently, governments and private companies looking to revitalize BIM have shown increased interest in developing automated evaluation and analysis technologies. Recent studies have also emphasized that BIM-based training and digital skill development are essential for improving practical implementation of automated evaluation systems in the construction industry (Sampaio, 2023). Additionally, there is a strong push to improve work efficiency in the construction industry by developing automated evaluation systems using BIM data (Park & Lee, 2020).

During the process of developing an automated evaluation system, methodologies for applying BIM data are programmed and developed considering certain evaluation and analysis calculation criteria (Jeong et al., 2020). Recent studies on automated geometric preprocessing have shown that BIM object consistency is essential for reliable rule-based quality control and model-based compliance evaluation (Bueno & Bosché, 2024). This study analyzes the spatial and geometrical characteristics of each major category of BIM models and classifies methods for their use based on BF-certification commentaries (Lee et al., 2025). Furthermore, the study aims to explore the automated evaluation process by classifying different types of BIM data for BF certification (Federico et al., 2023). The outcomes will be used to develop various automated evaluation methods, which will make the system development process for automated evaluations more efficient (Chong & Zhang, 2021).

Based on this research gap, this study makes three main contributions: (1) structuring BF certification criteria into BIM-compatible rule logic, (2) developing automated BIM-based evaluation methods, and (3) verifying applicability through a real BIM model.

2. BF certification and BIM research concept of BF certification

2.1. Concept of BF certification

The concept of BF certification focuses on creating an inclusive environment that accommodates the needs of all building users, regardless of physical ability or age (BF Guide). The primary aim is to promote independence and safety by ensuring that both buildings and facilities are accessible to everyone. BF certification eliminates barriers that impede access or usability and creates a user-friendly and inclusive environment. This study explores how BF certification can be integrated into architectural design and highlights its role in making spaces accessible to different user groups (such as the elderly and people with disabilities).

Moreover, architectural education increasingly emphasizes the importance of BF certification, promotes more awareness among architects, and encourages their responsibility for inclusivity and accessibility from the design phase (Zaslascky et al., 2023). Incorporating a BF certification strategy from the early stages of design is essential to ensure that spaces meet accessibility standards and address potential obstacles early in the process. Hence, there is a need for professional design tools that help architects integrate BF certification features into their projects while considering local characteristics and public interests. In architectural evaluations, accessibility can be prioritized by considering both the physical and socioeconomic factors that determine the usability of facilities (Song & Kim, 2020). Furthermore, a comprehensive evaluation process ensures that the building design caters to the diverse needs of its users. This study aims to integrate accessibility considerations into the design and evaluation processes by developing specialized tools to create an inclusive, accessible built environment.

2.1.1. Principles of barrier-free certification

The growing awareness of the need for accessible environments drives the concept of BF certification. This is especially important given the aging population and the increasing number of individuals with disabilities globally (Lee et al., 2012). BF certification is founded on design principles that ensure accessibility, safety, and usability for all individuals (Heylighen et al., 2017). These principles, listed in Table 1 below, provide a framework for designing and evaluating accessible spaces.

The BF certification principles are designed to promote independence, improve quality of life, and ensure that all buildings and facilities are suitable for all individuals, regardless of their physical capabilities. In other words, these principles emphasize the importance of designing spaces that are accessible, usable, and safe for everyone.

2.1.2. BF certification procedure

Barrier-Free (BF) certification ensures that buildings, parks, and other facilities provide a barrier-free living environment. BF certification involves various assessments and

Table 1. Principles of BF certification

Principle	Description
Function	Ensure an environment that provides the necessary support while avoiding unnecessary burden on users. This principle focuses on creating a space that helps individuals perform their daily activities efficiently and comfortably
Flexibility	Design an environment that accommodates the diverse needs and preferences of various users. This flexibility allows for different configurations and adjustments to meet individual requirements
Access	Remove physical barriers that prevent individuals from accessing and using the environment. This principle ensures that all areas are accessible to people of various physical abilities
Safety	Design should consider both physical and mental safety. This principle includes ensuring a safe environment for all users by recognizing potential risks and implementing measures to mitigate them

screenings to verify user accessibility from the design stage. It is generally divided into two stages: preliminary certification and main certification. The BF certification process follows a step-by-step procedure, as shown in Figure 1. The left side of Figure 1 illustrates the preliminary certification procedure during the design submission stage, where BIM model data are introduced as an alternative to conventional 2D drawing-based document preparation. The right side presents the main certification procedure after construction completion, where as-built BIM data can support final compliance review together with installed facility verification.

In this study, we propose a method to streamline the certification process by utilizing BIM data during the certification submission and application stages. By replacing traditional 2D data with BIM data, we propose a more efficient method for BF certification by automatically extracting the necessary information from the BIM model for document preparation and submission.

In this study, the BIM-based proposal method is positioned at both certification stages to reduce repetitive document preparation and improve consistency in certification data submission.

2.1.3. BF-certification item-classification system

Table 2 outlines the classification system for objects and spaces applicable to BF certification. Certification begins by categorizing the building facilities into six main groups: 1. Exterior Connection Facilities, 2. Internal Facilities, 3. Sanitary Facilities, 4. Information Facilities, 5. Other Facilities, and 6. Providing joint Supplies, as shown in Table 2. These categories are further divided into specific sub-classifications, including access roads, parking lots, main entrances, general access doors, corridors, stairs, ramps, elevators, disabled toilets, toilet access, urinals, sinks, bathrooms, showers, changing rooms, guidance systems, alarms, evacuation equipment, guest rooms, spectator seating, reception desks, information desks, ticket offices, vending machines, and other convenience facilities such as rest areas for pregnant women and providing joint supplies.

Each item is evaluated based on specific criteria such as the facilities' availability, height, width, materials, finishes, and connection methods designed to enhance accessibility for people with disabilities. The evaluation criteria and calculation standards are specified for each item. This study aims to develop a methodology that utilizes BIM data to meet these calculation standards more efficiently.

2.2. Current status and utilization of BIM-attribute information

The use of Building Information Modeling (BIM) is rapidly spreading across the architecture and construction industries due to its ability to manage and streamline complex construction projects (Volk et al., 2014). BIM integrates various aspects of construction data, from structural and material specifications to project schedules and costs, into

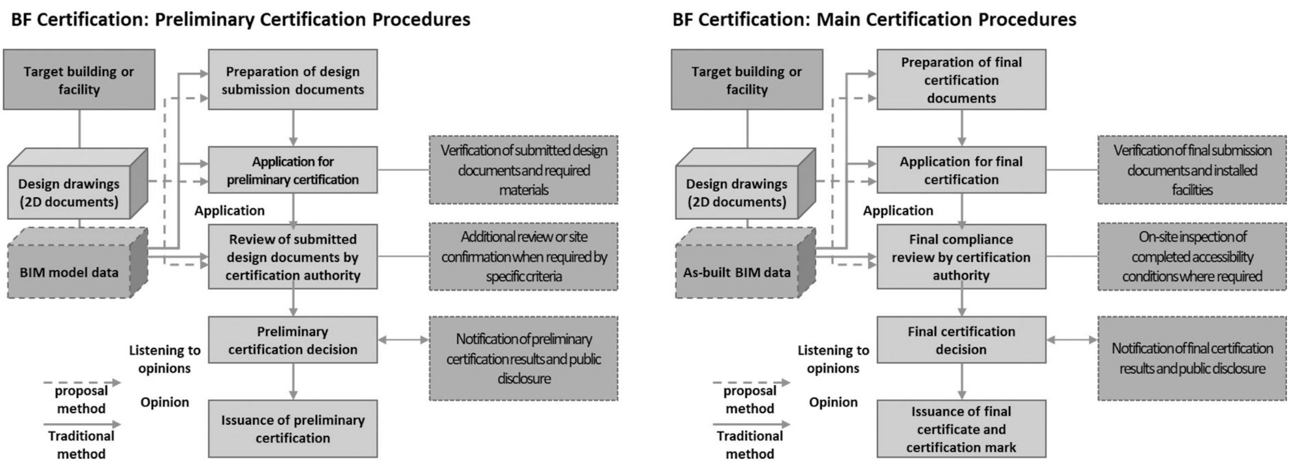


Figure 1. BIM-supported workflow for preliminary and main BF certification procedures

Table 2. BF certification item classification system

Large Category	Medium Category	Small Category
Building		
	1. Exterior Connection Facility	1.1. Access Road 1.2. Parking Area for Persons with Disabilities 1.3. Main entrance (door)
	2. Internal Facilities	2.1. General Entrance 2.2. Corridor 2.3. Stairs 2.4. Slope 2.5. Elevators
	3. Sanitary Facilities	3.1. Toilets for Disabled People 3.2. Access to Toilets 3.3. Toilet Bowl 3.4. Urinary System 3.5. Washbasin 3.6. Bathroom 3.7. Shower and Changing Rooms
	4. Information Facilities	4.1. Guided Equipment 4.2. Alarm and Evacuation Facility
	5. Other Facilities	5.1. Rooms and Bedrooms 5.2. Spectator and Reading Seats 5.3. Reception Desk and Information Desk 5.4. Ticket Distribution Box, Beverage Stand 5.5. Installation of Evacuation Spaces 5.6. Rest Facilities for Pregnant Women
	6. Providing Joint Supplies	6.1. Providing Joint Supplies

a single model (Mill et al., 2013). This enables easier collaboration among architects, engineers, and contractors, which reduces the potential for miscommunication and errors during the design and construction phases (Ghaffarianhoseini et al., 2017).

Over the past decade, interest in BIM within the construction industry has grown dramatically, with its usage rate increasing from 13% to 73% (NBS Enterprises Ltd., 2020). The many benefits of BIM, including improved project coordination, reduced errors, and enhanced overall project management, have driven this growth period (Wu et al., 2023). BIM enables better decision-making at all project stages, from design through post-construction management, by visualizing buildings in 3D models. Furthermore, BIM allows for real-time updates, which enables stakeholders to respond quickly to changes, minimizes delays, and avoids cost overruns. BIM also offers the ability to extract and analyze detailed data and images that are tailored to user needs. Unlike traditional CAD-based methods, BIM is object-oriented and uses architectural data to provide accurate and comprehensive information about a building's performance and design features (Li et al., 2024). BIM effectively reduced risks by detecting and resolving design flaws early. It also supports better team communication, reducing inconsistencies and aligning project goals.

However, despite the numerous benefits of BIM, the design certification process still heavily relies on traditional CAD drawings. It still requires data in CAD format, which necessitates converting BIM data to CAD format (Alsehaimi et al., 2024). This added step not only increases the complexity of the process but also undermines the potential efficiencies that BIM can bring to certification. In order to address this challenge, this study explores optimizing the use of BIM data in design certification. Data verification, production systems, and optimization algorithms are evaluated to improve BIM data management during certification (Kim et al., 2023). The goal is to directly utilize BIM models without relying on 2D CAD drawings, thus increasing the accuracy and reducing the time required for certification approval.

2.3. Utilization of BIM-attribute information

The information and attribute data of evaluation objects can be utilized from BIM data depending on the Barrier-Free BF certification evaluation items. BIM information classification can be divided into two main types: object-classification system-information and attribute-classification-system information. This information is structured to systematically support the evaluation process – see Table 3.

Object classification system information is subdivided into spatial-object information and part-object information. Spatial-object information provides details related to the location or range of space used to define specific areas within a building. In contrast, part object information offers detailed information about each object's specific position or component (Hong & Kim, 2018). This information is processed into BIM program classification items and is a critical element in automated BF certification review processes. The classification of object classification information ensures that attribute information can be efficiently utilized during the automated evaluation process (Wu & Zhang, 2019).

Attribute-classification-system information consists of four primary attributes. Identification attributes indicate information such as the presence or definition of objects. For instance, they can be used to confirm whether essential facilities are present in a specific space. Shape attributes provide information related to the physical form of objects, such as dimensions, area, length, and slope. This helps ensure that building elements meet the correct size and location requirements within a space.

Furthermore, physical attributes represent the materials' characteristics, which enables the evaluation of whether the material meets BF certification standards. Finally, reference attributes provide additional information about the object's functions or other related properties, which are used to review the additional requirements that buildings must meet.

During the BF certification evaluation, the evaluation object's classification and attributes are examined to ensure compliance with certification standards. In addition, BIM data allows the location of evaluation objects to be identified, and the required specifications and functions can be reviewed automatically. The classification of spaces is essential because evaluation criteria differ depending on spatial function and circulation conditions.

2.4. Need for BIM automation research

The necessity for BIM-based automated analysis and evaluation research has become a significant focus area in the architecture and construction industry due to the need to improve accuracy, efficiency, and scalability in design evaluation (Zhang, 2020). BIM for automating various evaluation processes (particularly in areas such as design certification, regulatory compliance, and building performance analysis) has gained attention when simplifying traditionally manual and labor-intensive tasks (Yang et al., 2013). Current research in this field is focused on leveraging the rich data models BIM provides to automate building design evaluations according to specific criteria, such as universal design, energy efficiency, and safety regulations (Ozturk, 2019).

Research into automated analysis and evaluation using BIM data demonstrates the potential for enhanced conformity with standards. The BIM's ability to integrate building data in a 3D object-oriented format provides a tool for automating design evaluations (Kim et al., 2013a). Automated tools are currently developed to extract information directly from BIM models, conduct real-time evaluations, and generate reports without manual intervention. Recent studies have validated the feasibility of automating evaluations for specific architectural standards, such as universal design and BF certification (Jin & Guo, 2021). These tools allow for identifying issues like non-compliance with accessibility standards or safety risks early in the design process, which enables more accurate and efficient evaluations (Yang et al., 2022).

The primary advantage of BIM-based automation is its ability to reduce human errors that are common in manual certification and review processes (Jung et al., 2013). By automating the extraction and analysis of design data, these tools ensure that all relevant information is reviewed against predefined criteria, which provides more reliable results (Rojas et al., 2019). Moreover, automation enables scalability, allowing large-scale projects or multiple buildings to be evaluated simultaneously with minimal additional effort (Meng et al., 2014).

As summarized in Table 4, recent BIM automation research generally follows several major development streams, including automated rule-based evaluation, regulatory integration, and data interoperability improvement (Kim et al., 2019). These research streams demonstrate that BIM automation is evolving from simple object extraction toward structured decision-support systems capable of supporting design verification under increasingly complex regulatory conditions (Laali et al., 2022).

However, despite these developments, relatively limited research has addressed how certification criteria themselves can be systematically transformed into BIM-compatible rule structures for accessibility-oriented certification systems such as BF certification. This indicates a remaining methodological gap between BIM-based object processing and certification-oriented evaluation logic.

Accordingly, the present study positions BF certification as a rule-based methodological application domain in which BIM object information, spatial conditions, and certification requirements must be jointly interpreted within a unified evaluation framework (Yoo et al., 2016). BIM-based automation therefore has the potential to become a vital tool for simplifying and improving the accuracy of architectural design evaluations. In addition, in BF certification, automated tools utilizing BIM data can minimize human error, identify problems earlier in the design phase, and enable more efficient evaluations. Moreover, future research into BIM data standardization and interoperability

Table 3. BIM properties information

Classification of information	Generated information	Description
About the Object Classification System	Space Object	Location
	Partial Individual	Exact Location, Object Name
Attribute Classification System Information	Identification Properties	Presence / Absence
	Shape Properties	Size, Area, Length, Slope, etc.
	Properties of Physical Properties	Material
	Reference Properties	Other Reference – Properties, Features

Table 4. BIM research types

Research Type	Description
Development of Automation Evaluation	Researchers are developing algorithms and processes that automatically evaluate accessibility standards, environmental performance, and structural safety (Choi & Kim, 2017). These studies automatically evaluate BIM models to save time and ensure evaluation consistency (Oh et al., 2019)
Integration with Regulatory Standards	Efforts are made to integrate BIM automation tools with regulatory standards such as building codes, energy performance standards, and safety regulations (Lee & Park, 2021). This enables automated evaluation to meet legal and industrial standards (Kang et al., 2022)
Data Interoperability and Standardization	Research is being conducted to improve the interoperability of BIM data and build standardization so that BIM models can be applied to various evaluation tools and platforms (Kim & Choi, 2016).
Rule-based Compliance Checking	Recent BIM studies convert regulatory requirements into machine-readable rule sets for direct comparison between BIM object data and compliance criteria, improving consistency in design review (Solihin & Eastman, 2015)
BIM-based Decision Support for Certification	Recent BIM research supports certification-related decision making through object filtering, spatial interpretation, and automated reporting, extending BIM use beyond model checking (Solihin & Eastman, 2016; Zhang & El-Gohary, 2017)

will likely broaden the application of BIM-based automation in certification-oriented design evaluations (Kim et al., 2016). The classification of spaces remains essential because evaluation criteria differ depending on spatial function and circulation conditions.

3. BIM-based BF building data

3.1. Characteristics of BF-users by type

Barrier-Free (BF) certification considers the needs of various user groups, including children, the elderly, pregnant women, people with disabilities, and temporarily disabled individuals. More specifically, the certification process classifies users into seven categories, as outlined in the BF certification guidelines. According to these guidelines, the certification requirements for each user type, such as infants, elderly individuals, wheelchair users, and visually and hearing-impaired persons, are detailed in Table 5. This table also outlines how BIM data can be utilized for each user's needs.

For instance, BIM libraries can be used to search for objects like strollers, nursing rooms, and ergonomically designed furniture for children and infants. For pregnant women, the placement of resting areas and seating arrangements can be evaluated. For elderly users, information about materials used for anti-slip flooring and the presence of handrails can be assessed. Wheelchair users and individuals with limited mobility can benefit from BIM-based shape analysis to evaluate ramp slopes and the presence of level changes. Moreover, BIM libraries

Table 5. How to utilize BIM data by BF-certified user type

User Type	Description	Leveraged BIM data
Infants and Children	Infants and children are in the early stages of life. They are often viewed as unique individuals who require the physical and cognitive support of their caregivers	Confirmation and arrangement of furniture specifications for infants
Pregnant Women	Pregnant women undergo many physiological and emotional changes during pregnancy. Common symptoms such as fatigue, low back pain, and difficulty walking can make maintaining a sense of balance challenging	Placement of resting areas and seating arrangements; presence of maternity amenities
Old Adults	The elderly are generally characterized by vulnerable groups with a high probability of medical conditions, cognitive decline, and physical decline. Daily tasks that will pose problems to them are tasks that require physical strength and continuous effort, often related to indoor and outdoor activities	Material attributes of anti-slip flooring; presence and dimensions of handrails
Wheelchair Users	Wheelchair users often face challenges as they negotiate level changes and move in narrow and crowded spaces	Shape analysis of ramp slopes and level differences
Ambulance for Individuals with Disabilities	People with temporary or permanent walking disabilities often experience unstable and slow movements	Convenience of movement, recognition, and specifications for installing assistive equipment
Blind Individuals	Blind people rely on the reduced ability of their vision as well as other aids to navigate	Ensure convenient access by evaluating steps, slopes, and pathways. Identify and assess potential obstacles
Deaf Individuals	As deaf people do not receive audio information, all information must be conveyed through alternative methods. This includes replacing audio alerts with visual signals and allowing users to customize the frequency and intensity of auditory cues.	Specifications for the installation of mobile convenience facilities

can help evaluate tactile, auditory, and olfactory signals, such as tactile blocks and alarm systems for visually impaired individuals. Visual alarm systems can be assessed for hearing-impaired individuals. While the objectives of BF certification differ for each user type, the classification of methodologies can be established by considering user characteristics and leveraging commonalities in BIM-data utilization.

3.2. Utilization of BIM data by facility for BF certification

BF-certification evaluation items are classified into five categories based on the facility type and the presence of necessary equipment. These categories are outlined in Table 6 and include exterior connection, interior, sanitary, informational, and other facilities, with an additional classification for facility supplies required for BF certification.

Exterior Connection Facilities refer to building accessibility from external spaces, such as roads and parking lots, to the building's interior. These areas are evaluated using spatial and floor-related BIM data. Interior Facilities refer to doors and passageways within the building to ensure they meet both size and obstruction-free requirements. Sanitary facilities are concerned with restroom accessibility, including the appropriate placement of disabled and child-friendly fixtures. Informational Facilities refer to whether visual, auditory, and tactile guidance systems are accessible to all users, while Other Facilities include guest rooms, lounges, and viewing areas. Lastly, Facility Supplies relate to barrier-free designs, such as slip-resistant finishes.

For automated BF certification, facility-specific attributes are identified, and the applicable BIM data are summarized in the third column of Table 6. In all cases, spatial data were used to categorize facility locations, while object attribute data were used for comparisons with evaluation standards. These rule categories demonstrate that automated evaluation requires combined interpretation of object presence, placement, and attribute information.

3.3. Utilization of BIM Data by object for BF certification

The BF certification evaluation guide analyzes and categorizes evaluation items based on different objects. These objects are broadly divided into five categories: space, architectural objects, information systems, and materials – see Table 7. The classification method is essential because the evaluation methodology for each object is similar, and the required data is consistent, which necessitates the categorization of objects accordingly (Yu & Choi, 2023). In addition to architectural elements, convenience and guidance facilities are also included in the BF certification evaluation items.

Spaces are classified into external spaces (outside the building) and internal spaces (inside the building). Architectural elements are categorized into eight subcategories (excluding structural components), which focus on elements with which building users can directly interact. For instance, floor elements are evaluated for their slip resistance, height differences, and slopes, including transitions from sidewalks to main entrances and interior areas. Walls are checked for effective width and the presence of obstacles. Stairs are evaluated based on effective width, clearance, and user-friendly dimensions. Ramps are assessed for their slope angles. Handrails are evaluated for their presence and dimensions, particularly in staircases, ramps, and corridors, to assist individuals with mobility challenges. Automatic doors are assessed for their effective width and functionality to ensure easy access for all users. Elevators are checked for compliance with specifications and the presence of alert systems to enhance safety and accessibility. In addition, furniture used in buildings is evaluated for adherence to relevant certification criteria to ensure it meets the needs of various users.

Moreover, information systems, such as auditory guides, Braille signage, and visual alarms, are evaluated as facilities that provide information. The presence and correct placement of tactile paving is also assessed to ensure effective guidance for individuals with visual impairments.

Table 6. BIM-data search method by BF certification facilities

Classification	Description	BIM Search Method
1. Exterior Connection Facilities	Access road, disabled parking area, main entrance	Building Outer Space Area, Sidewalk Floor Standard
2. Internal Facilities	General entrance, corridor, stairs, ramp, lift	Building Interior Space Area, Sidewalk Floor Standard
3. Sanitary Facilities	Toilets available to persons with disabilities, access to toilets, toilets, toilets, toilets, toilets, washbasin bathrooms, showers, and change-ups	Bathroom room information, accessibility
4. Information Facilities	Information equipment, alarms, and evacuation equipment	Search for objects in common space, lobby area, information facility facilities
5. Other Facilities	Rooms and bedrooms, bleachers and reading, reception desk, Ticket office, vending machine, beverage stand, evacuation zone, maternity rest facility	Room space area, search with space classification code, search with amenities objects
6. Providing joint Supplies	6 Co-Supply Provisions	Find co-supplied product objects

Table 7. How to use BF certification by BIM object category

Main Category	Detail Category	Description
Space	Exterior	Access and movement outside
	Interior	Internal access, movement, and use of facilities
Building Objects	Slab	Remove obstacles to ensure pedestrian safety when passing
	Wall	Guidance devices for convenience when using facilities
	Stair	Remove obstacles and safety devices for movement between floors
	Ramp	Walkable slope and safety devices
	Railing	Assistance for users' access and use of facilities
	Door	Access and space as a medium for connecting spaces
	Lift	Convenience when using the lift
	Furniture	Provide ease of use for facility users within the building
Information Systems	Information System	Display signs, including Braille signs and informational content
	Braille Block	Raised block format for tactile guidance
Convenient Facilities	Dedicated Instrument	Facilities and systems specifically designed for persons with disabilities
Quality of Materials	Material	Material and finishes that provide anti-slip protection
	Visibility	Ensuring visibility for risk and guidance

Convenience facilities, such as resting areas, are evaluated for their availability and suitability for users to promote comfort and accessibility. Additionally, aspects such as slip resistance, temperature (coldness), texture, and visibility are checked for compliance with relevant standards. These evaluation criteria can be effectively assessed by searching and comparing the names, classification systems, shape attribute data, and functionalities of BIM objects.

3.4. Utilization of BIM attribute data for BF certification

BIM design data provide essential information for the evaluation process related to BF certification. These data can be classified into three main attribute systems that support automated BF certification evaluations, as summarized in Table 8. BIM data are categorized into three primary classifications: space, object, and attribute. These classifications are instrumental in analyzing building features to ensure compliance with BF guidelines.

Space Classification applies to building areas, floors, and spaces, which allows evaluators to readily check whether accessibility standards are met. For instance, corridors, ramps, and restrooms can be identified and assessed for proper placement and dimensions. As shown in the image, spatial objects define the location and extent of various building spaces, such as floors, zones, and rooms. These space arrangements are then evaluated to determine if they meet the accessibility standards based on the BF certification criteria.

In addition, Object Classification focuses on the physical components of a building, such as walls, doors, and windows. These elements are used to check whether the requirements for door width or surface materials (essential for wheelchair accessibility) are met. Part objects provide detailed information about the physical components within the building, such as columns, walls, doors, and windows, which enable evaluators to assess whether these objects are correctly arranged to ensure accessibility. The image highlights examples of doors and windows that can be evaluated to determine whether they meet the BF certification standards.

Finally, Attribute Classification provides detailed specifications, such as material types, dimensions, and physical properties of building elements. This attribute is used to check if materials meet the BF certification standards and functional requirements. Attribute Classification is divided into identification attributes, shape attributes, physical properties, and reference attributes, each providing specific information related to the building's functionality or material. In the image, a screen (displaying attribute information) is shown, with details such as material properties and design attributes that play a critical role in the automated evaluation process.

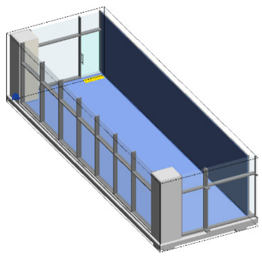
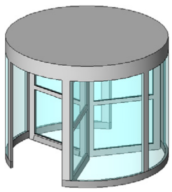
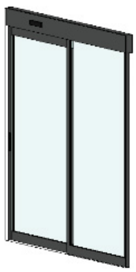
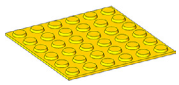
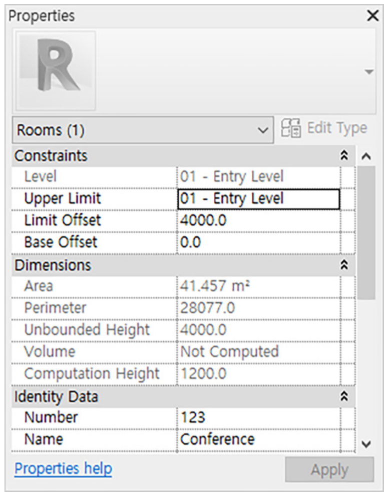
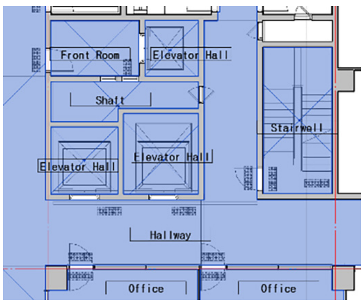
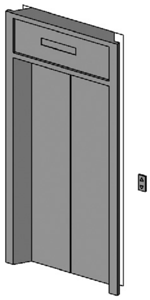
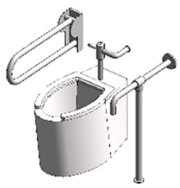
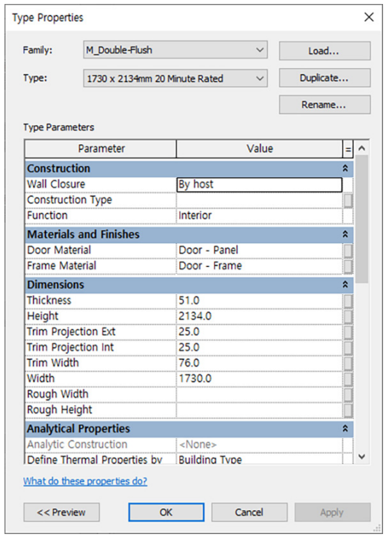
A comprehensive and automated evaluation of a building's compliance with BF certification can be performed using BIM's attribute-based classification system. Building designers and evaluators can then integrate space, object, and attribute data to ensure that all aspects of the building meet the required accessibility standards. By leveraging this BIM-based classification system, the accuracy and efficiency of BF certification can be improved significantly, which reduces reliance on manual reviews and enhances the overall quality of the design.

4. Data analysis for automated BF evaluation

4.1. Types of data analysis for automated BF evaluation

In order to implement automated BF certification using BIM, the structure of the BF-certification evaluation guide was applied to confirm that characteristics and evaluation criteria vary according to different user groups. Each facility has unique specific evaluation factors, and the evaluation methods are similar across different facilities.

Table 8. Utilization of BF certification data by BIM attributes

<table>
<tr><td>Classification System</td><td colspan="3">Object Classification System</td><td>Attribute Classification System</td></tr>
<tr><td>Detailed Classification</td><td>Spatial Object</td><td colspan="2">Part Object</td><td>Attribute Information</td></tr>
<tr><td rowspan="2">Image</td><td></td><td></td><td></td><td>
</td></tr>
<tr><td>
</td><td></td><td></td><td>
</td></tr>
<tr><td>Content</td><td>Define the location and scope of various spaces, such as floors, areas, and rooms of buildings</td><td colspan="2">Used to physically construct facilities, such as columns, walls, doors, windows, etc.</td><td>Identification properties, shape properties, building properties, and reference properties</td></tr>
<tr><td>BF Certification</td><td>Use when classifying the area and scope of facilities and evaluating the location of evaluation items and the criteria for the scope of utilization space</td><td colspan="2">Evaluation objectives according to criteria and the arrangement of evaluation objects</td><td>Comparison of specification and material values of evaluation criteria, functional evaluation of calculation criteria</td></tr>
<tr><td>Leverage BIM data</td><td>Project information, levels, spatial data, and compartment areas</td><td colspan="2">Object shape data, object shape property values</td><td>Identification, shape, property, and reference property values</td></tr>
</table>

BF certification categorizes evaluation criteria based on user characteristics, spatial requirements, and building objects. BIM data are then utilized to search, extract, and compare information for automated analyses. This process is divided into four distinct rules for automated analysis: space search, object search, object placement, and attribute extraction.

First, spatial classification analysis involves evaluating the building layout and space composition criteria. The analyzed BIM components include spaces such as rooms, corridors, and open areas. The critical analysis focuses on ensuring the required facilities are present and sufficient space is allocated to meet accessibility requirements. The result of this analysis is a comparative evaluation of whether the necessary spaces exist and whether they meet BF standards.

Second, shape analysis is based on building elements' physical geometry and dimensions. BIM components, such as ramps, doors, and stairs, are evaluated to ensure that their shape and dimensions meet accessibility requirements. This analysis involves comparing parameters like slope and width to assess whether all building shapes comply with the BF standards.

Third, placement analysis evaluates how objects are positioned in the building according to the evaluation criteria. The BIM components in this analysis include objects like signs, seating, and tactile indicators. The focus is on verifying these objects' correct placement and utility in compliance with BF guidelines, which ensures that the evaluation objects meet the accessibility requirements.

Lastly, attribute analysis focuses on building elements' material properties and specifications. This analysis examines the BIM model's material data, dimensions, and other functional attributes to determine whether they align with BF certification standards. Critical aspects like material durability and functionality are then compared against BF requirements to verify compliance. The analysis results confirm whether the materials and attributes used in the building do indeed meet the required accessibility standards.

By classifying BIM data into space, shape, placement, and attribute analyses, this approach can provide a comprehensive methodology to perform automated BF evaluations. Furthermore, by separating the utilization of BIM data according to the evaluation criteria, the methodology can be applied systematically, which results in more efficient research in automated evaluation processes.

The classification of BIM data into spatial, geometric, placement, and attribute analyses establishes the minimum analytical framework required for automated BF certification evaluation. Each category corresponds to a different type of certification requirement and determines how BIM information should be extracted and compared during rule-based evaluation. This classification also provides the methodological basis for the automated evaluation procedures presented in the following section.

4.2. Methods of automated evaluation by type

(1) Spatial classification analysis

The evaluation items for BF certification differ according to the facility's spatial function, which makes spatial search methods crucial. Such spatial classifications facilitate the evaluation of structure items based on similar criteria, which makes them easier to review at the evaluation stage. Moreover, BF certification provides guidelines for a wide range of evaluation criteria, including mobility-related access and movement requirements within facilities. These include requirements for areas such as accessible restrooms, emergency evacuation spaces, and designated parking for people with disabilities. More specifically, BIM space data include room names, numbers, types, areas, volumes, and textual information on finishes, flooring, and wall treatments. These data allow the system to automatically search for the facilities required for BF certification. This workflow demonstrates that spatial information must be classified before evaluation criteria can be applied systematically (see Figure 2).

(2) Geometric analysis for automated review

BIM objects contain 3D geometric information that can be configured with parameters. Automated analysis can be performed by examining the geometry itself along with its parameter values. Geometric data, such as dimensions (width, height, depth), slope, as well as color, can be extracted and evaluated. For example, floor slopes can be analyzed using slope parameter values. For the BF certification, a geometric analysis assesses the effective width of doors to ensure that entryways meet the accessibility requirements. The automated analysis also verifies if objects are appropriately sized and placed at user-convenient heights, particularly for individuals with physical limitations. These evaluations are conducted by extracting the parameter values of objects from the BIM model. Geometric analysis is essential because dimensional compliance forms the basis of several BF certification items (see Figure 3).

(3) Object placement for automated review

The object placement evaluation determines whether certain objects are present and appropriately placed within a BIM project based on relevant certification standards. For example, the placement of informational signage at building entrances or tactile paving blocks at stair entrances and exits for visually impaired individuals can be assessed automatically. In addition, the BIM model can be searched to confirm whether the necessary objects are present and correctly positioned according to BF certification requirements. The system can also evaluate whether designated spaces, such as parking areas for people with disabilities, are placed near building entrances and appropriate placement criteria are met. Placement verification enables automated confirmation of object accessibility under predefined certification conditions (see Figure 4).

(4) Attribute analysis for automated review

In addition to geometric parameters, BIM data can provide additional information about building elements, such as area, perimeter, surface area, location details, material types, and functional attributes. These data can then be used to evaluate whether the building elements meet the functional requirements for BF certification. For example, the automated system can verify whether a door has accessibility features (e.g., an automatic opener) and whether it is appropriately placed within the building. Moreover, the review process filters all doors within the BIM model to identify the primary entrances. Once filtered, the system evaluates whether these entrances meet BF certification requirements, such as minimum effective width and adequate clearance both in front and behind a door. Attribute verification complements geometric analysis by incorporating functional information required for certification judgement (see Figure 5).

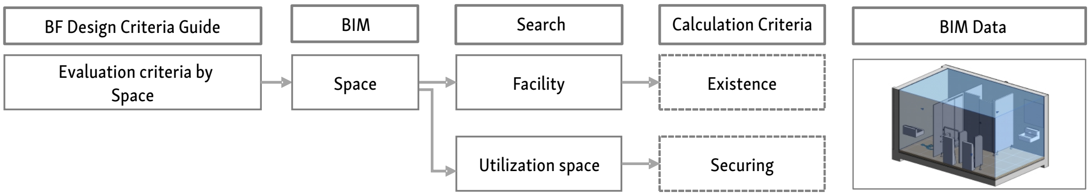


Figure 2. BIM-based spatial classification workflow for BF certification evaluation

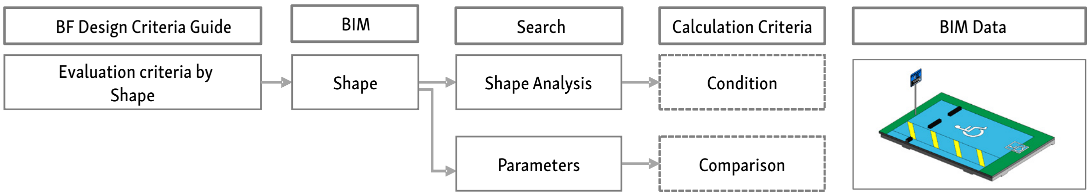


Figure 3. BIM-based geometric analysis workflow for BF certification evaluation

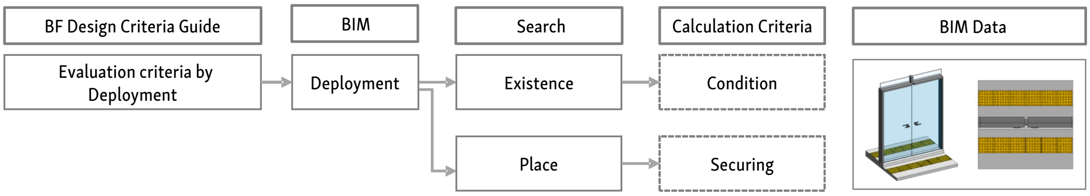


Figure 4. BIM-based object placement verification workflow for BF certification

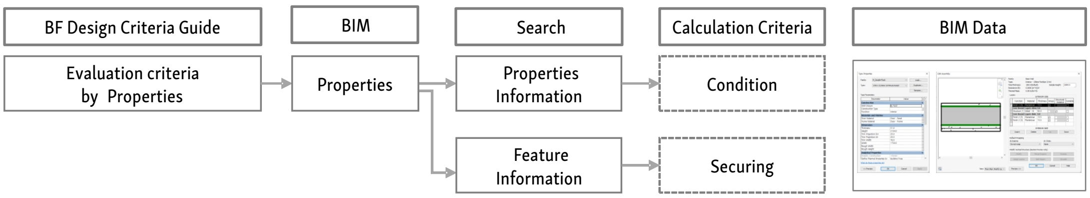


Figure 5. BIM-based attribute information verification workflow for BF certification

Overall, BIM-based automation offers a comprehensive approach to ensuring facilities comply with BF certification standards. By classifying analyses into space search, object placement, geometric analysis, and attribute evaluation, the system can verify a building's compliance with accessibility requirements both systematically and efficiently. Automated approaches reduce the need for manual inspections, increase evaluation accuracy, and streamline the certification process, which ultimately contributes to a more inclusive environment.

5. Automated evaluation process for BIM-based BF-certification

5.1. Types of automated analysis processes

In this study, the automated evaluation process for BF certification was classified based on the evaluation methods shown in Table 9. The evaluation methods were organized by object type for BF certification and focused on the necessary information from BIM data. Furthermore, the analysis methods were divided into three categories according to output criteria, which yielded the automated analysis process types below.

To create the automated analysis process, we first referenced the BF certification guidelines to understand and analyze the evaluation methods. BIM data were then used to classify the evaluation objects and their occupied spaces. Subsequently, the BIM information was analyzed based on the output methods to compare and evaluate against the BF certification criteria. Note that not all analysis methods are identical, and some evaluations may simply verify the presence of objects, while others require confirmation that objects are placed correctly within spaces according to BF certification conditions. Different data and conditions are needed depending on the evaluation scenario. BIM Geometry and BIM Information were used for each scenario, categorized by type, and summarized in Table 9.

The column for the BF-certification evaluation criteria can include seven evaluation types, while the rows list evaluation methodologies, BIM objects, BIM spaces, presence, placement, and attribute information. Each evaluation type contains items marked with a circular object.

Table 9. Automation analysis process types for BF design

Evaluation Criteria	BF Design Criteria Guide	BIM Geometry		BIM Information		
	Evaluation Method	Object	Space	Presence	Deployment	Parameters
Presence of an Object	(A)	O		O		
Presence of Space	(A)		O	O		
Object is Present in Space	(A) / (B)	O	O	O		
Place Objects in Space	(A) / (C)	O	O		O	
Objects that Meet the Criteria	(A) / (D)	O	O			O
Objects that Meet the Criteria Exist in Space	(A) / (B) / (D)	O	O	O		O
Place Objects in Space that Meets the Criteria	(A) / (C) / (D)	O	O		O	O
Calculation Criteria	(A) Presence, (B) Securing, (C) Condition, (D) Comparison					

To study the evaluation methods for BIM-based BF certification, we divided the types into seven categories and documented how the geometry and information aspects of BIM can be used in each evaluation method.

(1) Verification of Object Presence:
This method checks if the object is present within the project. For example, it verifies if an automatic ramp is installed on a slope or an elevator is installed instead of stairs. This approach is suitable for evaluation items that only need to confirm the presence of objects within the building without additional conditions.

(2) Verification of Space Presence:
This method checks whether the necessary spaces for BF certification, such as designated restrooms or accessible parking spaces, exist in the project.

(3) Verification of Object Presence in a Specific Space:
This method confirms whether an evaluation object is present in a specific space. For example, it verifies whether seating areas are placed outdoors or whether accessible sanitation facilities are present in designated restrooms for individuals with disabilities.

(4) Verification of Object Placement in Space:
This method checks whether the evaluation object is placed in a specific space and meets the required conditions. For instance, it evaluates whether tactile paving is correctly installed at the beginning of a stairwell.

(5) Verification of Objects that Meet the Criteria:
This method verifies whether the evaluation object meets specific attribute conditions. For example, it assesses whether handrails comply with required height, material, and circumference specifications to ensure user safety.

(6) Verification of Objects that Meet the Criteria Present in Space:
This method determines whether an object that meets specific attribute conditions is present in a particular space. For example, it verifies whether a voice-guidance system is installed in an elevator space and whether the function is operational.

(7) Verification of Objects Placed in Space that Meet the Criteria:
This method evaluates whether an object that meets certain conditions is appropriately placed in a specific space. For example, it checks whether a guidance system is installed at the main entrance with good visibility and whether the guidance information is displayed correctly.

The various evaluation types were organized into methods for finding and comparing the presence, placement, and attribute information of objects and spaces within the BIM. We can further refine automated evaluation techniques by developing a process based on these methods. By adjusting input data and conditions, more comprehensive evaluations can be achieved.

5.2. Automated evaluation and analysis process

In this study, the automated evaluation method for BF certification was programmed and applied to a 10-story building via a sample file. The openBIM Research Group provided this sample file as a test model for automated support technology based on openBIM architectural design. However, because the base design did not include all the features necessary for BF certification, additional modifications were made to the BIM design data. For example, ramp slopes were adjusted, door widths were modified for easier access, and additional guidance systems and facilities for individuals with disabilities were installed. BIM-based BF certification evaluations were then conducted using these data – see Figure 6. Relevant objects and information were searched and extracted from the BIM model following the BF certification guide. Subsequently, the data were compared and analyzed against the BF evaluation criteria. This process demonstrates that BIM object classification must precede rule-based certification checking.

5.3. Application of the BF automated evaluation

This study classified BF certification data to assess the convenience and accessibility of buildings. For example, the process of determining whether tactile paving blocks are installed for visually impaired users is described in Figure 7. BIM data were categorized, and objects with door functionalities were filtered to verify the availability (presence) of tactile paving near the doors. The filtered data were then used to conduct an automated evaluation and determine compliance with BF standards.

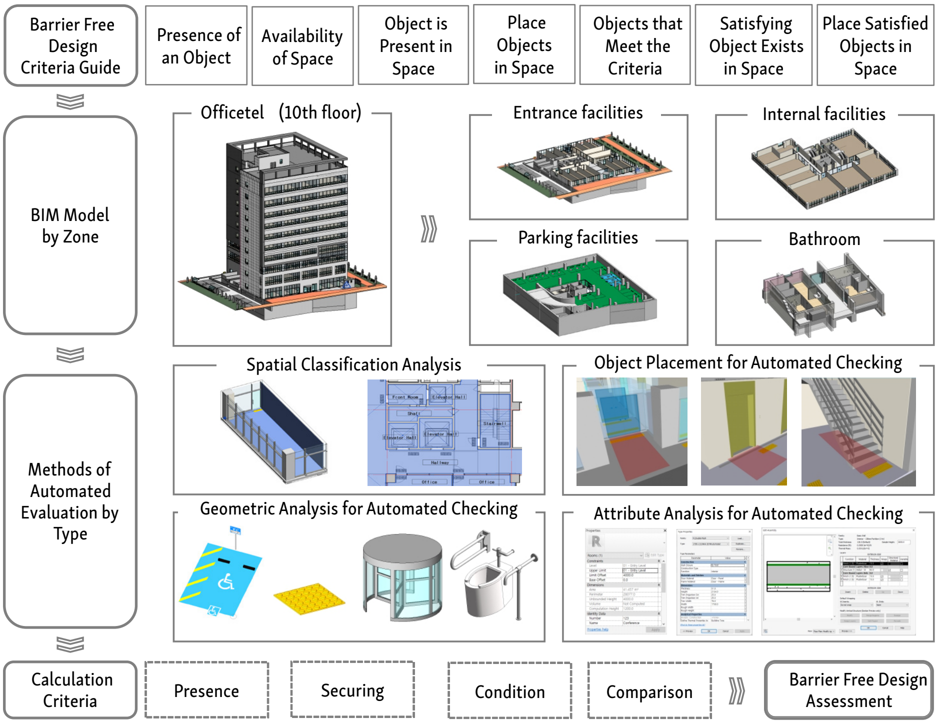


Figure 6. Automated evaluation and analysis process

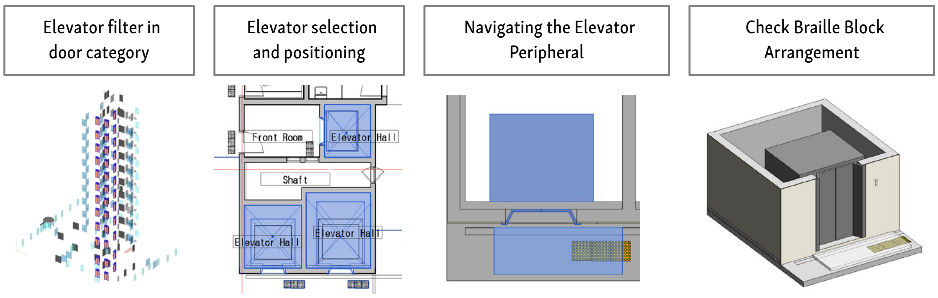


Figure 7. A methodology for evaluation of braille block arrangement in front of elevator

A geometric analysis evaluation method is shown in Figure 7. This method involves analyzing the geometry of filtered objects, such as evaluating the accessibility of the space in front of an elevator. The elevator doors were located, and a virtual space centered on the elevator was established to check for obstructions. This BIM-based evaluation method is far more efficient than manual evaluations based on drawings and can be automated using programmed processes.

This process demonstrates that BIM object classification must precede rule-based certification checking.

5.4. Application of the BF automated evaluation

During the analysis of the design data in this study, it was confirmed that the objects for BF certification evaluation are diverse, and these objects occupy a significant number of elements in each design project. For example, as summarized in Table 10, the 10-story building sample that the openBIM Research Group provided contained 68 space data points, 253 doors, 1,265 walls, and approximately 1,232 pieces of furniture and equipment for BF certification evaluation. It is essential to correctly link and analyze object and space data by category. This allows for identifying the locations of the 253 doors in relation to the 68 space data points and assessing whether these objects interfere with or affect other equipment or facilities. Such vast amounts of data can be efficiently analyzed using an automated evaluation process that is programmed to follow specific rules.

The automated evaluation method using the BIM data presented in this study has certain advantages compared to conventional 2D evaluation methods – see Table 11. Firstly, BIM data contain not only spatial information but also attribute information about objects, which enables evaluators to analyze design data much more efficiently. In particular, BIM data include three-dimensional geometric information that allows for automatic search and filtering of space arrangements, object sizes and shapes, materials, and other attributes. Therefore, searching based on BIM objects and filtering attribute information enables comparative assessments during the evaluation process.

Table 10. Number and utilization of project BIM object categories

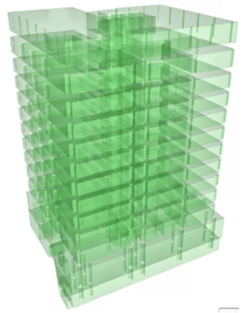
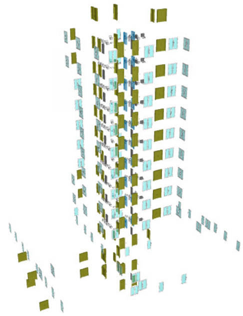
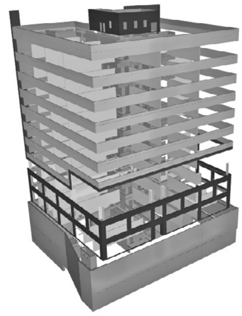
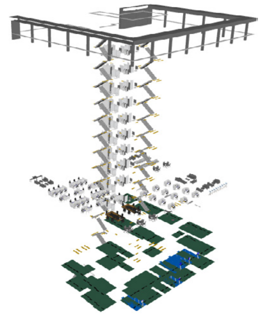
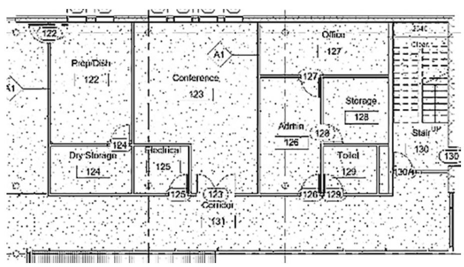
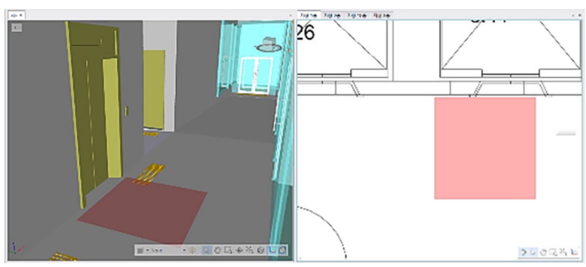
Category	Space	Door	Wall	Furniture Facilities
Image				
Pieces	68 Pieces	253 Pieces	1265 Pieces	1232 Pieces
For BIM utilization	Determine the name and characteristics of the evaluation area	Search for door objects and compare their inquiry property values	Check the wall-to-wall spacing and identify obstacles around the wall	Search for objects and households for BF certification goals

Table 11. Comparison of authentication methods using 2D and 3D data

Comparison of Methods	2D Data Comparison	3D Data Comparison
Image		
Data Type	Floor plan, elevation, sectional view, material schedule, and detailed view	BIM project files and automation evaluation program
Preparation in Advance	No pre-preparation work	Development of automation evaluation logic required
Evaluation Method	Manual search for evaluation objects	Automated search based on BIM objects, followed by comparative evaluation after filtering attribute information
Checking Time	253 x 30 seconds = Total 7590 seconds	60 seconds
Future use	One-off project per evaluation	Evaluation logic is reusable for future assessments

In addition, developing logic is essential for facilitating automated evaluations.

Furthermore, the BIM-based evaluation method significantly reduces evaluation time. While two-dimensional data require manual verification of each object, BIM data enables automatic searching of objects and analysis of attribute data through programs, which significantly speeds up the evaluation process. For example, the time required to evaluate 253 objects can be reduced to only one minute. Although this may vary from project to project, BIM-based evaluation methods generally allow for faster and more accurate evaluations, which improves overall project efficiency considerably.

Finally, BIM-based evaluation methods are not limited to individual projects but can also be reused for other projects based on the established evaluation logic. This strengthens the automation of design evaluations and contributes to long-term improvements in design quality. For example, once a specific evaluation logic is developed, it can be applied directly to similar projects in the future and save both evaluation time and cost.

However, the standardization of BIM data is pivotal and enables the application of consistent evaluation criteria across various projects. While the initial development of an automated evaluation system requires investment, it can significantly reduce human error and significantly improve both project quality and efficiency in the long term.

Therefore, compared to traditional 2D evaluation methods, BIM data enable more intuitive, rapid, and accurate evaluations, which emphasizes the importance of automation in architectural design certification evaluation. It was confirmed that automated evaluation using BIM data offers a more efficient, faster, and more reliable method than manual 2D evaluations, with significant benefits for improving the quality of design certifications. However, both standardizing BIM modeling and maintaining data consistency are necessary. Moreover, each designer's approach or each design company's method for constructing BIM models may vary, which makes it essential to establish unified standards and guidelines to address these discrepancies.

The application results confirm that the proposed rule-based BIM extraction process can efficiently identify certification-related objects and spatial conditions across a large BIM dataset. In the sample project, approximately 18,000 BIM objects were processed, and 253 door-related objects associated with 68 spaces were evaluated within approximately 60 seconds, demonstrating substantial reduction in repetitive checking time compared with conventional document-based review. These results indicate that the proposed framework does not merely automate object extraction but establishes a structured evaluation logic that directly links certification criteria, spatial conditions, and BIM object attributes within a single rule-based process.

6. Discussion

6.1. Practical significance of BIM-based BF certification

The proposed BIM-based evaluation process demonstrates practical advantages in reducing repetitive manual interpretation during BF certification review. In conventional certification workflows, evaluators manually identify spatial dimensions, object types, and installation conditions from two-dimensional drawings, which requires repeated checking of multiple drawing sheets and often causes omission of relevant items. In contrast, the proposed method enables direct extraction of certification-related objects and spaces from BIM data according to predefined rule categories, thereby improving consistency during the review process.

The application of the proposed method showed that 253 door-related objects associated with 68 spatial entities were evaluated within approximately 60 seconds, whereas equivalent manual review required approximately 7,590 seconds. This difference demonstrates that BIM-based automation is particularly effective for repetitive certification tasks involving multiple object relations and dimensional checks, especially where a large number of objects must be verified simultaneously.

From a broader governance perspective, the proposed BIM-based BF certification process reflects a preventive and non-disruptive transition logic. By identifying accessibility-related deficiencies during the design stage, the process reduces late-stage redesign, administrative burden, and uncertainty for designers, evaluators, and applicants. This gradual and capacity-aware improvement logic aligns with the CalmMobility paradigm proposed in sustainable transition studies, which emphasizes incremental adaptation, error prevention, and user-centred institutional improvement rather than corrective intervention after implementation. This indicates that the technical value of BIM-based automation extends beyond object-level checking by supporting earlier and more consistent certification decisions within the overall review process. In this sense, the proposed system can be interpreted not only as a technical support tool but also as a mechanism for improving certification governance through earlier and more stable decision-making. As shown in Table 12, the proposed BIM-based process differs fundamentally from conventional document-based review in terms of information source, object identification, spatial verification, and evaluation efficiency. This comparison demonstrates that BIM-based evaluation reduces repetitive interpretation steps while improving consistency in accessibility-related review tasks.

6.2. Technical limitations of automated BIM evaluation

Despite its efficiency, the proposed method depends on a minimum level of BIM modelling consistency. Automated evaluation requires that object names, family classifications, and parameter definitions be properly assigned during modelling. If BIM objects are inconsistently named or required attributes are omitted, rule-based extraction may not correctly identify evaluation targets.

Another limitation is that the current method assumes certification criteria that can be explicitly translated into object-based rules. Evaluation items requiring subjective judgement, contextual interpretation, or visual confirmation may still require manual expert review. Therefore, automated evaluation should be understood as a support mechanism for improving efficiency rather than a complete replacement for professional certification judgement.

In practical projects, differences in modelling conventions across software platforms and project participants may also affect the reliability of automated checking.

Table 12. Comparison of conventional BF certification review and BIM-based automated evaluation

Evaluation aspect	Conventional certification review	BIM-based automated evaluation
Information source	2D drawings and documents	BIM model data
Object identification	Manual checking of drawing elements	Automated extraction from BIM objects
Spatial verification	Manual measurement and interpretation	Rule-based spatial analysis
Evaluation time	Approximately 7,590 sec	Approximately 60 sec
Risk of omission	Possible due to manual interpretation	Reduced through automated checking

For broader implementation, additional BIM standardisation and preprocessing procedures may be required.

In addition, the current method is most effective for certification items that can be explicitly formalized into object-, space-, or attribute-based rules. Items requiring qualitative judgement or contextual interpretation remain difficult to automate fully. The proposed process therefore assumes a minimum level of BIM standardization, and its direct transferability to other certification systems may require adaptation of object classification rules and regulatory criteria according to local certification frameworks.

6.3. Future applicability of the proposed method

Although the present study focuses on BF certification during the design stage, the rule-based classification framework may also support broader BIM-based compliance applications. Because the proposed framework combines object filtering, spatial condition analysis, and rule-based verification, it provides a methodological basis that may be extended to BIM4D environments where accessibility conditions depend on construction sequence, temporary circulation, and staged installation. Recent BIM4D studies have demonstrated that object-based scheduling and lifting verification can be integrated with rule-based BIM analysis, suggesting broader applicability beyond certification review (Huang et al., 2022). Similar object filtering and spatial condition analysis could be applied to universal design review, green building certification, and selected construction-stage accessibility verification tasks.

In particular, future integration with BIM4D environments may enable accessibility review linked to construction sequencing, temporary circulation planning, and staged installation verification. This suggests that the proposed method has potential applicability beyond static design checking, particularly in construction processes where accessibility conditions change over time.

Future research should also examine interoperability under openBIM environments, particularly IFC-based object mapping, in order to improve transferability across software platforms and regulatory systems.

7. Conclusions

As global populations age and demographic structures become increasingly diverse, the importance of Barrier-Free (BF) certification in architectural design and facility planning continues to grow. At the same time, the increasing adoption of Building Information Modeling (BIM) in the architectural industry creates opportunities to improve conventional certification workflows through data-based automation. In response to these developments, this study proposed a BIM-based automated evaluation process for BF certification by structuring certification criteria into programmable BIM data extraction and object classification logic.

To establish the automated evaluation methodology, BF certification criteria were systematically classified according to user characteristics, facility types, and object conditions. User categories included infants, older adults, individuals with mobility limitations, visually impaired users, hearing-impaired users, and general users, allowing evaluation logic to reflect diverse accessibility requirements. In parallel, BIM data were categorized according to spatial conditions, object types, placement relations, and attribute requirements, enabling direct linkage between certification criteria and BIM object information.

Based on this classification framework, seven evaluation methods were established, including space search, object search, placement verification, presence checking, and attribute extraction. These methods enabled automated comparison between certification requirements and BIM object data through rule-based evaluation logic. In particular, the classification of spaces and objects proved essential because certification criteria vary depending on spatial function, object use, and required installation conditions.

The proposed process was applied to a sample multistory BIM model to verify practical applicability. In the BIM model of a 10-story mixed-use building containing approximately 18,000 objects, the automated process identified 253 door-related objects associated with 68 spatial entities and completed evaluation within approximately 60 seconds, whereas equivalent conventional manual review required approximately 7,590 seconds. These results confirm that BIM-based automation can significantly improve efficiency in repetitive certification tasks while reducing omission risks during document-based review.

Despite these advantages, the method depends on a minimum level of BIM modelling consistency and predefined object properties. Differences in object naming, family classification, and parameter assignment may affect extraction reliability, and evaluation items requiring contextual judgement or visual interpretation still require expert review. Accordingly, the proposed framework should be understood as a BIM-based support system for improving certification efficiency rather than as a fully autonomous replacement for expert certification review.

While the present study confirms immediate practical gains in certification efficiency through rule-based BIM evaluation, future research should focus on improving BIM data standardization, expanding interoperability under openBIM environments, and extending the proposed framework to broader certification systems such as universal design and green building certification. In addition, future studies may examine integration with BIM4D-based construction environments to support accessibility evaluation across both design and construction stages.

Acknowledgements

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (RS-2025-00563716).

Funding

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (RS-2025-00563716).

Author contributions

Eunsang Yu was responsible for managing the BIM data used in the study, developing the methodology for automation of barrier-free (BF) certification using BIM, classifying evaluation types, and drafting the manuscript. Yonghan Ahn contributed by organizing the rationale for automated evaluation within BIM data, gathering practitioner feedback based on practical outcomes, and reflecting it in the study. Jungsik Choi, as the corresponding author and principal investigator, directed the research by defining its necessity and scope, and significantly contributed to the overall development and writing of the manuscript.

Disclosure statement

The authors declare that there are no competing financial, professional, or personal interests that could have influenced the work reported in this paper.

References

Alsehaimi, A., Waqar, A., Alrasheed, K. A., Bageis, A. S., Almujibah, H., Benjeddou, O., & Khan, A. M. (2024). Building a sustainable future: BIM's role in construction, logistics, and supply chain management. *Ain Shams Engineering Journal*, *15*(12), Article 103103. https://doi.org/10.1016/j.asej.2024.103103

BF Certification System. (2020). *Barrier-free living environment certification*: *Evaluation criteria and guidelines*. Korea Disabled People's Development Institute. https://www.koddi.or.kr/bf/data/cfDataList.do

Bueno, M., & Bosché, F. (2024). Pre-processing and analysis of building information models for automated geometric quality control. *Automation in Construction*, *165*, Article 105557. https://doi.org/10.1016/j.autcon.2024.105557

Choi, J. H., & Kim, I. H. (2014). A study on the application of pre-processing to develop the open BIM-based code checking system for building administration process. *Journal of the Architectural Institute of Korea Planning & Design*, *30*(9), 3–12. https://doi.org/10.5659/JAIK_PD.2014.30.9.3

Choi, J. S., & Kim, I. H. (2017). Development of openBIM-based quality checking system for evacuation regulation application. *Korean Journal of Computational Design and Engineering*, *22*(3), 329–337. https://doi.org/10.7315/CDE.2017.329

Chong, O. W., & Zhang, J. S. (2021). Logic representation and reasoning for automated BIM analysis to support automation in offsite construction. *Automation in Construction*, *129*, Article 103756. https://doi.org/10.1016/j.autcon.2021.103756

Dubljević, S., Tepavčević, B., Stefanović, A., Jezdić, K., & Anđelković, A. S. (2024). Opportunities and limitations for integration of the green building certification system in the BIM environment. In *2024 9th International Conference on Smart and Sustainable Technologies* (*SpliTech*), Bol and Split, Croatia. https://doi.org/10.23919/SpliTech61897.2024.10612602

Federico, G., Stefano, C., & Rosa, C. (2023). Integrating BIM processes with LEED certification: A comprehensive framework for sustainable building design. *Buildings*, *13*(10), Article 2642. https://doi.org/10.3390/buildings13102642

Ghaffarianhoseini, A., Tookey, J., Ghaffarianhoseini, A., Naismith, N., Azhar, S., Efimova, O., & Raahemifar, K. (2017). Building information modeling (BIM) uptake: Clear benefits, understanding its implementation, risks, and challenges. *Renewable and Sustainable Energy Reviews*, *75*, 1046–1053. https://doi.org/10.1016/j.rser.2016.11.083

Heylighen, A., Van der Linden, V., & Van Steenwinkel, I. (2017). Ten questions concerning inclusive design of the built environment. *Building and Environment*, *114*, 507–517. https://doi.org/10.1016/j.buildenv.2016.12.008

Hong, S. C., & Kim, S. T. (2018). A basic study on review the classification system and the process of BIM information for an automatic review of certification method of health and barrier-free environment. *Journal of the Korean Institute of Interior Design*, *27*(4), 154–165. https://doi.org/10.14774/JKIID.2018.27.4.104

Hong, S. H., & Kim, S. T. (2024). A basic study on the configuration of BIM templates for the barrier-free living environments certification: Focused on creating BIM models for architecture. *Journal of the Korea Institute of the Spatial Design*, *19*(4), 61–75.

Hong, S. W., & Park, J. Y. (2020). Effectiveness of BIM-based human behavior simulation on architectural design education: Focused on exploration and evaluation of barrier-free and fire evacuation performances. *Journal of KIBIM*, *10*(4), 1–10.

Huang, L., Pradhan, R., Dutta, S., & Cai, Y. (2022). BIM4D-based scheduling for assembling and lifting in precast-enabled construction. *Automation in Construction*, *133*, Article 103999. https://doi.org/10.1016/j.autcon.2021.103999

Jang, J. H., & Kim, D. K. (2016). A study on the improvement of barrier-free certification system. *Community Development Review*, *41*(2), 97–115.

Jin, C., & Guo, Z. (2021). Research on key technologies of railway electric and electronic systems engineering construction management based on BIM. In *2021 7th International Conference on Information Management* (*ICIM*) (pp. 24–29), London, United Kingdom. https://doi.org/10.1109/ICIM52229.2021.9417132

Jung, G. Y., Woo, J. W., Kang, K. D., & Shin, J. C. (2013). Reliability analysis and utilization of BIM-based highway construction output volume. *Journal of KIBIM*, *3*(3), 9–18. https://doi.org/10.13161/kibim.2013.3.3.009

Jeong, Y. N., Jae, H. J., & Tae, H. K. (2020). Implementation of property input automation program for Building information modeling (BIM) property set. *Journal of the Computational Structural Engineering Institute of Korea*, *33*(2), 73–79. https://doi.org/10.7734/COSEIK.2020.33.2.73

Kang, K. H., Son, B. H., & So, S. Y. (2022). BIM-based efficiency review of barrier-free certification items. *Journal of the Korea Institute of Building Construction*, *22*(2), 183–194. https://doi.org/10.5345/JKIBC.2022.22.2.183

Khoshdelnezamiha, G., Liew, S., Bong, V. N., & Ong, D. (2020). A BIM-based automated assessment tool for green building index. *IOP Conference Series*: *Materials Science and Engineering*, *943*(1), Article 012059. https://doi.org/10.1088/1757-899X/943/1/012059

Kim, J. H., & Choi, J. S. (2016). *Development of an automated BIM-based quality assurance system for architectural designs*. Korean Institute of Construction Engineering and Management.

Kim, M. H., & Koo, B. H. (2022). Study on deriving improvements through analysis of BF certification evaluation indicators for parks and park facilities. *Journal of the Korean Institute of Landscape Architecture*, *50*(5), 13–29. https://doi.org/10.9715/KILA.2022.50.5.013

Kim, I. H., Choi, J. S., & Jo, G. H. (2013a). *Developing automated code checking modules for BIM in super-tall buildings*. Korean Institute of Architecture. https://www.irbnet.de/daten/iconda/CIB_DC25807.pdf

Kim, J. G., Ryu, J. L., & Choo, S. Y. (2013b). An analysis on effectiveness of BIM-based area calculation method for improving quality of Korean apartment housing. *Journal of the Korean Housing Association*, *24*(2), 45–52. https://doi.org/10.6107/JKHA.2013.24.2.045

Kim, S. C., Yoo, J. H., Park, M. S., Lee, J. G., & Yeo, C. J. (2016). Introduction of the open BIM-based design collaboration and license application support system (KBIM submission). *Construction Engineering and Management*, *17*(4), 41–46.

Kim, Y. D., Choo, S., Seo, J. H., & Kim, T. H. (2019). An application of BIM-based mixed reality to improve BF certification. *Korean Journal of Computational Design and Engineering*, *24*(2), 211–222. https://doi.org/10.7315/CDE.2019.211

Kim, G. T., Kang, G. J., Yu, E. S., & Choi, J. S. (2023). A research on the generation of BIM data requirement property information for green building certification. *Korean Journal of Computational Design and Engineering*, *28*(4), 493–502. https://doi.org/10.7315/CDE.2023.493

Laali, A., Nourzad, S. H. H., & Faghihi, V. (2022). Optimizing sustainability of infrastructure projects through the integration of building information modeling and envision rating system at the design stage. *Sustainable Cities and Society*, *84*, Article 104013. https://doi.org/10.1016/j.scs.2022.104013

Lee, B. H. (2016). A study on the improvement of design process for obstacle-free living environmental certification. In *Proceedings of the Academic Conference of the Korean Society for Ecological and Environmental Architecture*. Korean Society for Ecological and Environmental Architecture. https://www.auric.or.kr/User/Rdoc/DocRdoc.aspx?returnVal=RD_R&dn=340950

Lee, C. Y., Shim, U. J., & Ahn, Y. S. (2012). A basic study on review the classification system and the process of BIM information for an automatic review of building code. *Journal of Construction Engineering and Project Management*, *13*(5), 45–52. https://doi.org/10.6106/KJCEM.2012.13.5.045

Lee, J. H., & Park, M. K. (2021). *Integration of BIM automation with building regulatory standards for improved compliance*. Korean Society of Civil Engineers.

Lee, K.-S., Park, N.-Y., & Koh, I.-L. (2025). A study on the classification of information systems for BIM-based barrier-free living environment certification evaluation items in building permits (Seumtur). *Journal of Korea Academia-Industrial Cooperation Society*, *26*(8), 238–247. https://doi.org/10.5762/KAIS.2025.26.8.238

Li, W., Wu, P., Huang, J., & Xu, Y. (2024). A new paradigm for construction safety management in China: Introducing knowledge graph and accident database into the early-stage of BIM. *Journal of Cleaner Production*, *470*, Article 143367. https://doi.org/10.1016/j.jclepro.2024.143367

Ma, J. H., Yu, E. S., Ahn, Y. H., & Choi, Y. H. (2022). A study on evaluation item data classification for BIM-based BF certification evaluation. *Korean Journal of Computational Design and Engineering*, *27*(2), 126–136. https://doi.org/10.7315/CDE.2022.126

Maqsoom, A., ul Asad, B., Prasittisopin, L., Harbouz, I., Basharat, M. ul, & Saqib, S. E. (2025). BIM-driven safety: Automated rule-based multihazard detection and legal compliance in high-rise construction. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, *18*(2), Article 04525108. https://doi.org/10.1061/JLADAH.LADR-1409

Meng, Y., Li, X., & Ma, C. (2014). The application of fuzzy comprehensive evaluation based on AHP in the BIM application maturity evaluation. In *Proceedings of the ASCE International Conference* (*ICCREM 2014*) (pp. 280–286). ASCE. https://doi.org/10.1061/9780784413777.034

Mill, T., Alt, A., & Liias, R. (2013). Combined 3D building surveying techniques—terrestrial laser scanning (TLS) and total station surveying for BIM data management purposes. *Journal of Civil Engineering and Management*, *19*(Sup1), S23–S32. https://doi.org/10.3846/13923730.2013.795187

NBS Enterprises Ltd. (2020). *National BIM report 2020*. https://www.thenbs.com/knowledge/national-bim-report-2020

Oh, J. K., Lee, J. H., & Park, S. Y. (2019). *BIM-based environmental performance analysis for building certification*. Korea Institute of Building Science.

Ozturk, G. B. (2019). A measurement instrument for the technology extent and process efficiency in BIM enabled construction projects. In *Proceedings of International Structural Engineering and Construction*. ISEC Press. https://doi.org/10.14455/ISEC.res.2019.3

Park, M., & Lee, S. (2020). *BIM-based automated evaluation systems for construction efficiency*. Korea Institute of Civil Engineering and Building Technology.

Rojas, M. J., Herrera, R., Mourgues, C., Ponz-Tienda, J., Alarcón, L., & Pellicer, E. (2019). BIM use assessment (BUA) tool for characterizing the application levels of BIM uses for the planning and design of construction projects. *Advances in Civil Engineering*, *2019*, Article 9094254. https://doi.org/10.1155/2019/9094254

Ryu, S. O., Kim, I. S., & An, S. J. (2018). A study for problems and current status of standards about authentication of a barrier-free living environment (passenger facilities): Through related laws comparison and investigation. *Journal of the Korea Institute of Healthcare Architecture*, *24*(4), 37–45.

Sampaio, A. Z. (2023). BIM training course improving skills of construction industry professionals. *Procedia Computer Science*, *219*, 2035–2042. https://doi.org/10.1016/j.procs.2023.01.505

Shin, D. H. (2020). A study on improvement of ramp installation standard for BF certification. *Journal of the Korea Institute of Healthcare Architecture*, *26*(2), 31–38.

Solihin, W., & Eastman, C. (2015). Classification of rules for automated BIM rule checking development. *Automation in Construction*, *53*, 69–82. https://doi.org/10.1016/j.autcon.2015.03.003

Solihin, W., & Eastman, C. (2016). A knowledge representation approach in BIM rule requirement analysis using conceptual graphs. *Journal of Information Technology in Construction*, *21*, 370–401.

Song, Y. S. (2014). *BIM data integrity and interoperability in architectural systems*. Architectural Society of Korea.

Song, W., & Kim, C. (2020). Analyze the problems in the process of implementing barrier-free certification. *Journal of Urban Planning*, *11*(2), 95–104. https://doi.org/10.21447/jup.2020.11.2.95

Volk, R., Stengel, J., & Schultmann, F. (2014). Building information modeling (BIM) for existing buildings—Literature review and future needs. *Automation in Construction*, *38*, 109–127. https://doi.org/10.1016/j.autcon.2013.10.023

Widell, A. (2013). *Möjliga tillämpningar av BIM vid miljöcertifieringsarbete*. Environmental Certification Studies.

Wu, J., & Zhang, J. (2019). New automated BIM object Classification Method to Support BIM Interoperability. *Journal of Computing in Civil Engineering*, *33*(5), Article 04019033. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000858

Wu, X. G., Cao, Y., Liu, W. C., He, Y. B., Xu, G., Chen, Z. S., Liu, Y., & Skibniewski, M. J. (2023). BIM-driven building greenness evaluation system: An integrated perspective drawn from model

data and collective experts' judgments. *Journal of Cleaner Production*, *406*, Article 136883.
https://doi.org/10.1016/j.jclepro.2023.136883

Yang, H. H., Lee, M. H., Siao, F. C., & Lin, Y. C. (2013). Use of BIM for constructability analysis in construction. In *Proceedings of the Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction* (*EASEC-13*), Sapporo, Japan.

Yang, T. C., Xu, J., & Nie, X. (2022). Analysis of data exchange between BIM design software and performance analysis software based on Revit. *Journal of Physics*: *Conference Series*, *2185*, Article 012070. https://doi.org/10.1088/1742-6596/2185/1/012070

Yoo, J. H., Park, M. S., Lee, J. G., & Yeo, C. J. (2016). Introduction of the open BIM-based design collaboration and license application support system (KBIM submission). *Construction Engineering and Management*, *17*(4), 41–46.

Yu, E. S., & Choi, J. S. (2023). Development of building information modeling-based automation assessment process for universal design of public buildings. *Journal of Computational Design and Engineering*, *10*(2), 641–654.
https://doi.org/10.1093/jcde/qwad018

Yu, E. S., Ma, J. H., & Choi, J. S. (2021). A study on the automation application of BIM-based BF certification evaluation process. *Korean Journal of Computational Design and Engineering*, *26*(4), 418–427. https://doi.org/10.7315/CDE.2021.418

Yu, E. S., Ahn, Y. H., & Choi, J. S. (2023). A research on the generation of BIM data requirement property information for green building certification. *Korean Journal of Computational Design and Engineering*, *28*(3), 212–221.
https://doi.org/10.7315/CDE.2023.212

Zaslascky, F., Di Lucca, V. N., Peiró Aparisi, M., & Sofía, M. (2023). Importancia de la accesibilidad en la carrera de arquitectura: Construyendo espacios inclusivos desde la formación universitaria. *Revista Trayectorias Universitarias*, *9*(16), Article 125.
https://doi.org/10.24215/24690090e125

Zhang, H. (2020). Intelligent building planning system based on BIM and artificial intelligence. In *2020 International Conference on Intelligent Transportation*, *Big Data* & *Smart City* (*ICITBS*) (761–764), Vientiane, Laos.
https://doi.org/10.1109/ICITBS49701.2020.00167

Zhang, J., & El-Gohary, N. M. (2017). Integrating semantic NLP and logic reasoning into a unified system for fully automated code checking. *Automation in Construction*, *73*, 45–57.
https://doi.org/10.1016/j.autcon.2016.08.027