buildings

MDPI

Article

Implementation of an Automated Code Checking Algorithm Based on Site Analysis

Seong Jeongmin and Shin Sangyun *

Department of Architecture, Keimyung University, Daegu 42601, Republic of Korea; 1114334@stu.kmu.ac.kr
* Correspondence: sangyun@kmu.ac.kr; Tel.: +82-53-580-5341

Abstract: To date, BIM has been primarily utilized in cost and schedule management, an interference check between architectural and structural models and systems based on geometric data in the process of the construction life cycle. However, there is a lack of research that utilizes the information contained in the BIM model to review whether the proposed architectural model is appropriately designed in accordance with each country's building regulations or building codes or that proposes a model optimized for laws and standards. 'Building code checking' is the step of reviewing whether a building designed based on the building codes is suitable for being constructed as a building. However, this process consumes significant time and money and leads to human errors due to the manual review process. This study included implementation of an algorithm based on the Korean building code. In this study, there was the process of selection of codes when architects interpret building codes in common and implementation based on the codes selected. Next, modeling based on DXF files from NGII (National Geographic Information Institute) was applied to the algorithm developed in this study. Last, it includes case studies that compare the outputs of the algorithm with the real buildings, which had received real code checking, to make sure the algorithm in this paper is working properly. The implementation of such an automated system has the potential to significantly improve the efficiency and effectiveness of the building design and construction process. It can help architects to quickly and accurately identify potential legal issues and provide alternative solutions that meet regulatory requirements. This, in turn, can lead to reduced project costs, improved quality of designs, and faster project delivery times.

Keywords: building information modeling; building codes; generative design; automated code checking

check for updates

Citation: Jeongmin, S.; Sangyun, S. Implementation of an Automated Code Checking Algorithm Based on Site Analysis. *Buildings* **2024**, *14*, 1654. https://doi.org/10.3390/buildings14061654

Academic Editors: Soowon Chang, Youjin Jang and Jeehee Lee

Received: 16 April 2024
Revised: 23 May 2024
Accepted: 31 May 2024
Published: 4 June 2024

1. Introduction

Is it possible for the information required for tasks such as schematic design, maintenance, remodeling, or demolition of a building to be sufficiently satisfied with only the database (DB) embedded within building information modeling (BIM)? KIM et al. states that it is not feasible for BIM alone to manage all information due to the need for users to individually search for external information like building codes. Additionally, it has limitations due to varying standards demanded by building codes in accordance with the scale and characteristics of each construction project. Therefore, as unregulated information is introduced from external sources to convert architectural projects into BIM models, discrepancies in interpretation may arise depending on the users [1]. Therefore, it is necessary to establish a system that can interpret and process the external information in BIM.

Recently, the possibility for the adoption of generative designs (GDs) into BIM platforms to autonomously output masses based on an algorithm that comprehends and interprets the legal information required in architectural projects was suggested. In other words, it has the potential to generate optimal output by combining BIM and GD based on a code checking algorithm to automatically generate the code checklist that had to be manually entered [2]. As a result, by combining legal information with geometry data within BIM, optimized architectural plans are derived and output as 3D mass models.

These processes are expected to reduce the time and costs involved in code checking. Additionally, optimizing design proposals during the architectural planning phase will enhance the efficiency of architects' work.

After this possibility was suggested, related studies were proposed to apply it to the architectural field. However, KIM et al. stated that there were still limitations. First, there was a lack of other alternative output processes for inappropriate output and a process for manually interpreting building codes (Table 1). Thus, the there is a lack of output errors caused by manual processes. To supplement the limitations, this study includes a process for implementing an 'automated code checking' algorithm in BIM flatforms.

Table 1. Limitations of the existing 'code checking' research [3–6]. The underlined content is the limitations that this study aims to supplement.

Study Researcher (Year)	Limitations
Open BIM-Based Quality Control for Enhancing the Design Quality in the Architectural Design Phase. Seo, J. C., Kim, H. J., & Kim, I. H. (2012). [3]	1. Absence of automated code update 2. Need for detailed case studies of quality review
Development of Rule-Set Definition for Architectural Design Code Checking based on BIM—for Act on the Promotion and Guarantee of Access for the Disabled, the Aged, and Pregnant Women to Facilities and Information Kim, Y. R., Lee, S. H., & Park, S. H. (2012). [4]	1. Need for a survey for professionals 2. Absence of automated code update 3. Absence for inappropriate outputs
Trends in environmental building regulations and introduction of automated review programs. Park, C. Y., Jang, H. I., Lee, D. G., & Kim, K. S. (2018). [5]	1. Need for a comprehensive checking system 2. Absence of an automated code update 3. Absence of inappropriate outputs
Proposal of Development and Application of the Buildings by Use Classification System for openBIM-based Automatic Rule Checking Kim, I. H., Lee, S. J., & Choi, J. S. (2021). [6]	1. Only applications to use classification and area calculations 2. Absence of an automated code update

This study aims to develop an automated building code checking system using the algorithm proposed in this study during the schematic design phase, specifically legal information collection related to site analysis, and this involves inputting collected legal information into the model and generating alternative BIM mass models using GD. This study involves a process to achieve this purpose.

1. Literature review on how the system of the Korean building code is structured and what characteristics of BIM and GD can be used to apply it to BIM.
2. The selection process included the building code to be considered when implementing algorithms based on literature, buildings, and special-purpose areas that are in high demand and the process for implementing the 'building code checking algorithm'.
3. Case studies with BIM based on an actual site.
4. Discussion based on case studies.

The primary purpose of this study is to apply the advantages of combining an algorithm and GD to enhance the accuracy and productivity of the building code checking system. As a result, it aims to further expand the potential utilization of artificial intelligence technology in the field of architecture and enable more efficient architectural design and code checking tasks on-site.

2. Literature Review

2.1. The Definition of BIM

BIM (building information modeling) refers to simulating all architectural processes, from design and construction to maintenance and disposal, by generating a more accurate visual model in a multi-dimensional virtual space as digital files [7]. The main purpose of BIM is to specify design information so collaborators can easily understand and evaluate the designer's intentions and program, leading to quick decision making. It is an intelligent 3D model-based process that provides AEC (architecture, engineering and construction) professionals with a more efficient system for planning, designing, constructing, and managing buildings and infrastructure [8].

Conceptually, BIM can be characterized by three main features.

- It is a single or multiple file tool representing building information designed to be viewed with specific software. This aligns closely with the concept of BIM when it was first introduced.
- It encompasses the information processing and management processes throughout the lifecycle of a building. This has become the most prominent feature of BIM implementation in recent years, emphasizing implementation and management methods.
- It represents the concept of being a tool for building management from a software perspective, as emphasized in Autodesk's 2003 white paper [9] titled 'Building Information Modeling'.

In traditional architectural design drawings, the plan views and construction forms are separated based on bidding, and each is worked on separately. This format requires expertise from professionals in each field. However, it also leads to data processing problems and communication issues, resulting in errors such as delays and design changes during construction [10]. Such a lack of communication between parties causes significant disruption in the mutual benefits for building owners and users, highlighting the need for a system to facilitate smooth communication. Furthermore, there are difficulties in converting existing plan-based sketches into three-dimensional models. The conventional method of creating 3D models cannot capture all the information from plan views, often resulting in only rough representations of information such as wall positions or appearances. As a result, differences between the representations in executed drawings and those in 3D models were observed.

The concept of BIM emerged in the 1970s, as Eastman stated, in South Korea, and the adoption of BIM began to be encouraged by the Public Procurement Service (PPS) in 2009, which subsequently commissioned projects totaling KRW 4.354 trillion. Since 2016, the introduction of BIM has been mandatory for public construction projects, with the aim of applying BIM to up to 20% of SOC projects until 2020 [11]. However, as Kim stated, there are limitations to its application, particularly in large-scale projects like high-rise buildings, and also due to the lack of architectural design guidelines. Except for the governmental support, mainstreaming BIM requires cultivating numerous professionals or better accessibility through system integration. However, the exact number of professionals needed remains uncertain, and despite comprehensive educational support, it is unpredictable how many students will become proficient in existing BIM systems.

2.2. The System of Building Code in Korea

The Building Act, which is the building code in South Korea, places significant importance on defining the site, structure, facilities, and purpose of a building during the design process, emphasizing the functional elements, safety, and public interests of buildings [12]. The current structure of the Korean Building Act, as defined in the Ministry of Land, Infrastructure and Transport's "Architectural Administration Guidelines" in 2013, consists of four main stages. At the highest level is the Building Act, followed by the Building Act Enforcement Decree, six codes below that, and finally, the local government ordinances of each region [13].

Generally, the Building Act establishes general standards for buildings and related elements (such as land, building facilities, retaining walls, and other structures) and procedurally regulates the construction process of buildings. The legislative intent of the Building Act is to promote the economic and efficient use of buildings and enhance public welfare, particularly securing the safety of residential and living environments by regulating the purposes and types of buildings. The primary objective of the Building Act is to ensure the safety of citizens' lives, bodies, and property, similar to the content of the Police Act, by securing a safe state and preventing risks [14].

The details of the Building Act are delegated to multiple rules and ordinances, such as the Building Act Enforcement Decree, which specifies the scope and necessary codes for enforcement, and multiple rules and ordinances necessary for enforcement, such as the Building Act Enforcement Rules. Among the six rules corresponding to the Building Act Enforcement Rules are codes concerning structural and facility standards for buildings, codes concerning the registration and management of building registers, codes concerning the operation of standard design books, and regulations concerning standards such as fire escape structures for buildings. The enforcement rules specify the types of buildings for each purpose, divide them into categories, and regulate the scope of land where buildings can be designed, the structure and width of roads according to topographical conditions, the scope of plumbing lines, and materials for interior construction, among other aspects.

Local governments address many subordinate laws not explicitly specified in the Building Act, Enforcement Decree, or Enforcement Rules through ordinances, which specify the restrictions necessary for building design. In addition to these systems, other laws such as the National Land Planning and Utilization Act, Parking Lot Act, and Landscape Standards are also referenced and cited.

2.3. Automated Building Code Checking Based on BIM

In 2006, the United States initiated the SMARTcode project by the U.S. International Code Council (ICC) to develop an automated checking and approval process for U.S. building codes [15]. An example of BIM research conducted at the Georgia Institute of Technology (Georgia Tech, Atlanta, GA, USA) involved analyzing space programs independently using BIM technology from the planning phase of a courthouse building. This process involved analyzing design proposals from architects, conducting energy consumption analysis and evaluating the model, and finally, estimating the cost to review and address any issues.

In Singapore, there is an automated code checking process available through CORENET FORNAX. This system uses IFC and is divided into three web-based systems: e-submission, e-Information, and e-Plancheck. These systems are used for sharing business-related documents between private companies and the government. The analyzed results can be checked using the FORMAX Viewer [16].

Discussions have taken place in Korea regarding the automation of building code checks for the design of architectural schematic designs. This is based on the AIA exam automated evaluation system from the United States [17]. Since the 2010s, several studies have been conducted via open BIM to address issues such as evacuation codes, quality reviews, and classification methods for evacuation stairs [18]. Additionally, proposals have been made for rule sets based on model checkers to review laws aimed at improving convenience for vulnerable groups such as people with disabilities, elderly people, and pregnant women [4]. To regulate eco-friendly and energy-efficient buildings, several automated regulatory programs, including "Green Building Certification" have been introduced [5]. In 2021, a BIM-based building-usage classification system was proposed to review building permit codes [6]. Korea implemented a two-dimensional legality system through SEUMTER to establish a code checking system. Currently, basic research and pilot tests are being conducted to expand the application of BIM for SEUMTER reviews [3]. The Architectural Law Information Research Institute has provided a website-based automatic code checking system to minimize accessibility limitations in service provision. KIM et al. states that while previous research has developed rule sets and automatic code checking systems through open BIM, most studies lack alternative solutions for inappropriate outputs and still require manual input of codes, leading to risks of omissions and errors. To minimize these drawbacks, it is suggested to incorporate technology to reduce the scope of attribute work.

Recent research has suggested the possibility of interpreting the building code with a LLM (Large Language Model). In 2023, research that establishes the implementations of architectural civil complaints about building codes with LLM and the news that the 'Building Code QnA Support' system named 'Archilaws' has been implemented with ChatGPT in the auri(Architecture and Urban Research Institute in Korea) were carried out [19,20]. Based on this news, it is expected that an 'Automated Code Checking' system will be integrated with LLM and include generative A.I to reduce human error and automate code interpretation simultaneously.

2.4. The Use of Generative A.I. in Architecture

Generative AI is a type of artificial intelligence that can create results independently based on specific user requirements. It has a structure that allows it to generate output values using the algorithms it contains when given data values that it can understand. The most common method of implementing generative AI is using a generative adversarial network (GAN). It combines a generative network to produce new content and a discriminative network to interpret and evaluate existing content in its own way. The output values produced by GAN can take several forms, ranging from mathematical values derived through analytical processes, to outputs such as natural language processing and image generation through sketch recognition, among others [21].

In the schematic design phase, generative adversarial networks (GANs) are mainly utilized due to the design-oriented nature of the tasks. In 2021, a network was developed using GAN and Tensor Flow to enable Revit to understand freehand-drawn plan images. This network compares generated images with real images to create a building information modeling (BIM) model [22]. In recent years, AI-based image generation programs like Midjourney have made it possible to produce building exteriors based solely on keywords.

During the construction phase, discriminative networks based on GANs are primarily used to reduce errors in the design phase. In 2017, networks comprising generators and classifiers within GAN were utilized to analyze and reconstruct the porosity of stone materials, creating feasible training data [23]. Moreover, the Korea Land and Housing Corporation (LH) aims to analyze the state of AI-based construction technology and develop research strategies applicable to the industry based on networks created using GANs in 2017 [24].

3. 'Building Code Checking' Algorithm

3.1. Target and Model Settings

To implement the algorithm, it had to go through a process like that in Figure 1. In order to carry out the process in Figure 1, this study contained the following contents.

- The review of the building code system in Korea to select related code for site analysis.
- The current status of the existing code checking systems and the limitations of these systems that this study should supplement.
- The possibility of utilizing GD with code checking to output optimized results.

Although the above was used to implement the algorithm, it was inefficient to review buildings for all purposes at this step. Therefore, this study had to select the building and special-purpose area with the most demand. First, according to Article 19, Paragraph 4 of the Korean Building Act, buildings in Korea have been divided into nine facility groups depending on their intended purposes [25]. These groups are automobile related, industrial, electrical and telecommunications facilities, cultural and assembly facilities, commercial facilities, educational and welfare facilities, neighborhood living facilities, residential and business facilities, and others. Out of these groups, neighborhood living facilities (Class I & II combined) were the second most designed buildings in Korea, after single-family houses. Unlike single-family houses, which cannot be built in commercial distribution areas and exclusive industrial areas, neighborhood living facilities can be built in all usage zones. Therefore, neighborhood living facilities were selected as the subject of this study, considering their high proportion among all buildings and their ability to be built in all usage zones.

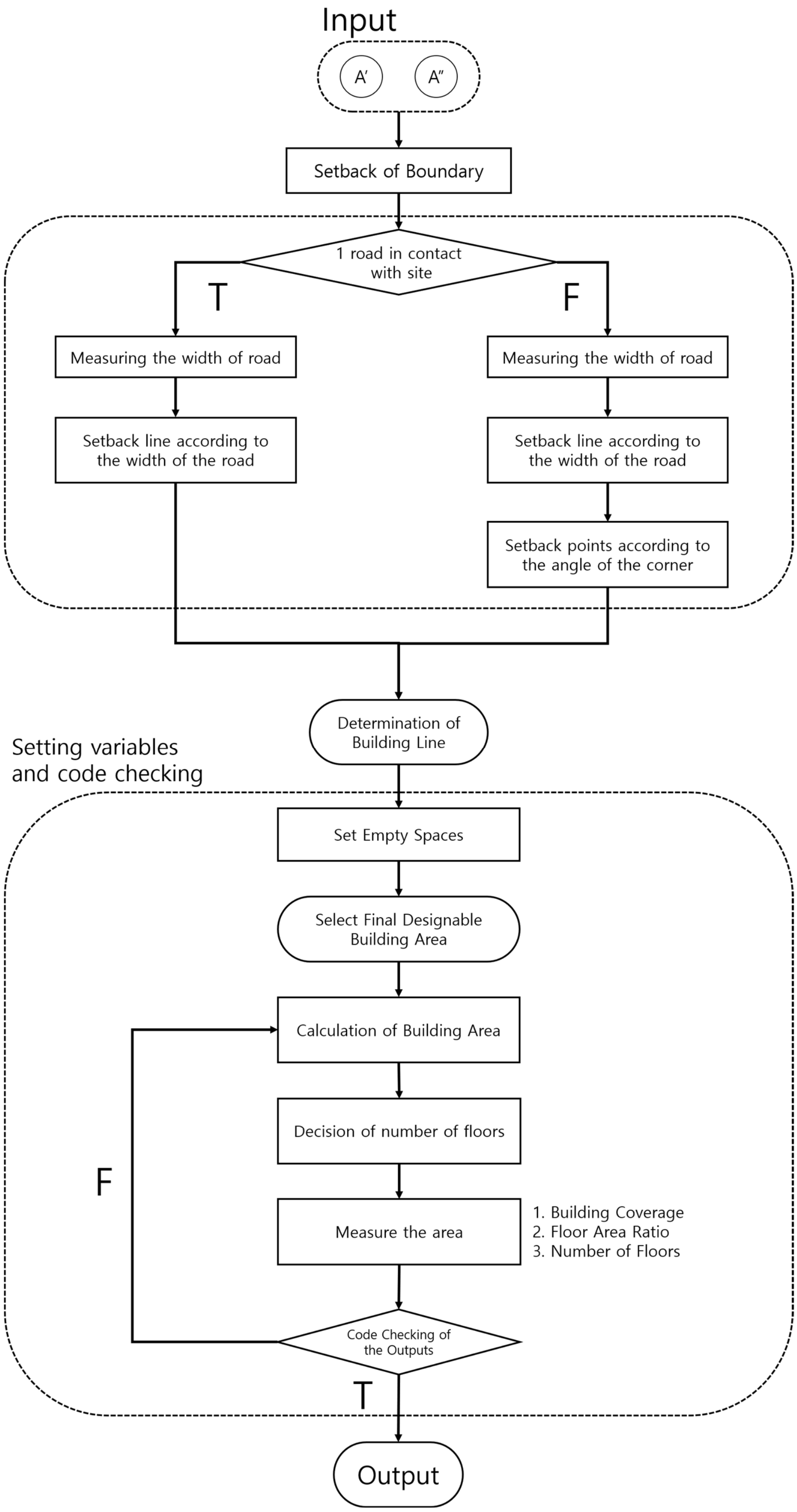

Figure 1. The Flowchart of 'Building Code Checking Algorithm': 'A′ refers to boundary of roads nearby, 'A″ refers to boundary of target site. The dashed line means the sectors of algorithm. The one above explains the process 'Determining 'Building Setback' and the other one explain 'Setting Variable for Outputs and Code Checking'. The letter 'T/F' means True or False to propositions.

In addition, to conduct research on designing neighborhood living facilities, some subordinate laws such as the Building Act, enforcement decrees, and local ordinances were selected as key analysis targets. Among the stages involved in the planning and design phase, site analysis was chosen as the main target, as it is the first and requires a comprehensive understanding. Therefore, the laws necessary for designing neighborhood living facilities include basic building design and site designation, open spaces at the site, landscaping, adjacent roads, and building-related laws such as the Building Act and its enforcement decree, the National Land Planning and Utilization Act, which specifies the floor area ratio and building coverage ratio for each facility, the Parking Act for establishing parking lots within the site, and other relevant local ordinances. A checklist was generated based on these codes.

To create a list related to site analysis from building codes, we needed to select the codes related to site analysis. The codes related to site analysis must be selected to create a list of building codes. Based on the data provided by the Korea Cadastral Survey Authority, we selected the Building Act, Building Act Enforcement Decree, and the National Land Planning and Utilization Act.

These codes were established to legally designate building lines, setbacks, and parking spaces. First, we reviewed the elements specified based on the Building Act and Building Act Enforcement Decree, including building line setbacks, setbacks, and adjacent site boundary lines (Table 2). Next, we selected elements that regulate open spaces beyond those in the Building Act, such as the Parking Act, to ensure that open spaces are secured within the site. Finally, we determined the allowable range of the building coverage ratio and floor area ratio for buildings by referring to Articles 84 and 85 of the National Land Planning and Utilization Act.

Table 2. List of laws about Schematic Design.

Category	Review	Building Code
Site and Roads	Building Line Setback	- Building Act. Article 46 - Enforcement Decree of The Building Act. Article 80
	Limitation	- Building Act. Article 47
	Landscape	- Building Act. Article 42 - Enforcement Decree of The Building Act. Article 25
	Safety	- Building Act. Article 40
Scale of Building	Building Coverage Ratio	- Enforcement Decree of the National Land Planning and Utilization Act. Article 84
	Floor Area Ratio	- Enforcement Decree of the National Land Planning and Utilization Act. Article 85
Urban Design	Citizen Participation Acquirement Open Space	- Building Act. Article 43
Open Space	Offset from Building Line Offset from Boundary Line	- Building Act. Article 58

From Enforcement Decree of the National Land Planning and Utilization Act. Article 76. The Limitation of Buildings in Special-Purpose Areas [26].

The target site modeling was conducted using existing addresses. The initial priority was to collect recent data files with sufficient information that could be input into BIM. The base for BIM was DXF files available from the Korea Cadastral Survey Authority. The target areas for modeling prioritized urban areas with information, such as road boundaries, widths of roads and angles of edges, available.

In the case of the neighborhood facility, almost all areas are suitable for establishment, and they are the second most constructed buildings after detached houses, shown as Tables 3 and 4. Therefore, this facility was selected as the most suitable building to represent this research's case study building. Based on data from early 2023, the target area for modeling was selected from downtown areas in Daegu City, which has had the highest proportion of zoning areas and is where neighborhood facilities can be built (Table 5). Therefore, one of the target areas meeting these conditions was selected, which resulted in the choice of the area around Banwoldang Station, represented by Namsan-dong 651-28 in Jung-gu. In this area, general residential areas and quasi-residential areas were mixed. To create the target site within the BIM model, the following steps were taken.

Table 3. The Usage of Buildings in Korea (2023).

Building Usage		**Number (1:1000)**	**Ratio**
Residential Building	Single-Family House	3502	58.9%
	Apartment	161	2.7%
	Multi-Family House	591	9.9%
	Row House	36	0.6%
	Multiplex House	256	4.3%
	etc.	29	0.4%
Commercial Building	Class I Neighborhood Living Facility	557	9.3%
	Class II Neighborhood Living Facility	634	10.6%
	Sales Facility	11	0.1%
	Business Facility	31	0.5%
	Lodging Facility	44	0.7%
	etc.	90	1.5%
Total		5942	

From Ministry of Land, Infrastructure and Transport [27].

Table 4. Buildings that can be designated special-purpose areas in Korea. The first line of this table refers to the usage of the building. 'A' refers to 'Class I Neighborhood Living Facility', 'B' refers to 'Class II Neighborhood Living Facility', 'C' refers to 'Single Family House', and 'D' refers to 'Apartment'.

The Usage Area	**A**	**B**	**C**	**D**
Class I exclusive residential area	**O**	**O**	**O**	**O**
Class II exclusive residential area	**O**	**O**	**O**	**O**
Class I general residential area	**O**	**O**	**O**	**O**
Class II general residential area	**O**	**O**	**O**	**O**
Class III general residential area	**O**	**O**	**O**	**O**
Quasi-residential area	**O**	**O**	**O**	**O**
Central commercial area	**O**	**O**	**O**	**O**
General commercial area	**O**	**O**	**O**	**O**
Neighborhood commercial area	**O**	**O**	**O**	**O**
Circulative commercial area	**O**	**O**		
Exclusive industrial area	**O**	**O**		**O**
General industrial area	**O**	**O**	**O**	**O**
Quasi-industrial area	**O**	**O**		

From the Enforcement Decree of the National Land Planning and Utilization Act. Article 76. The Limitation of Buildings in Special-Purpose Areas [26].

Table 5. The Special-Purpose Areas in Daegu (2022).

Usage		Area (1000 m^2)
Residential Area	Class I Exclusive Residential Area	289.8
	Class II Exclusive Residential Area	276.5
	Class I General Residential Area	26,270.7
	Class II General Residential Area	45,788.2
	Class III General Residential Area	33,552.6
	Quasi-residential Area	15,329.5
Commercial Area	Central Commercial Area	6883.5
	General Commercial Area	6454.3
	Neighboring Commercial Area	1438.0
Total		139,963.9

From DATA PORTAL. The Special-Purpose Areas in Daegu (2022) [28].

Only the layers related to modeling creation and review (such as roads, adjacent sites, contours, etc.) were kept from the DXF file, and an algorithm was used to generate the site modeling. Since DXF files contain excess site information besides what is necessary for site analysis, only the required information was retained to obtain the final site model.

3.2. Implementation of 'Building Code Checking Algorithm'

The primary purpose of this study is to complete automatic code checking using Dynamo based on the 3D modeling in Revit 2024. Initially, to obtain information about the site within a radius of 500 m from the target site, DXF files provided by the Korea Cadastral Survey Authority are obtained, and only necessary layers (site boundaries, roads, and road centerlines) was retained to create a Toposolid model in Revit.

Firstly, Figure 2(1) represents the setback of road boundaries in Dynamo Script. Among the layers extracted from the DXF file, values corresponding to each item (site boundaries, roads) were selected. For the site boundaries, setback distances were set according to each local ordinance. For roads, the process involved determining how many road elements are adjacent to the site and measuring the length vector of each road.

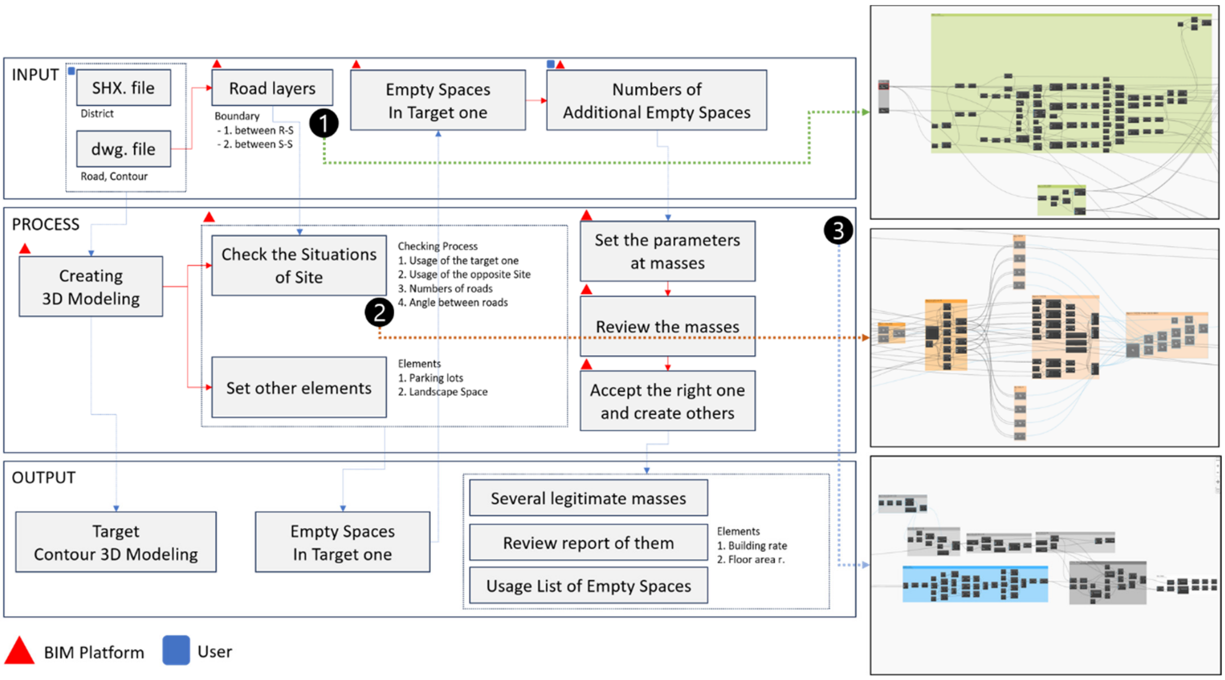

Figure 2. Implementation Process of Algorithm and Detailed Script.

After this measurement process, the setback lines within the site and roads were outputted, and the intersection points of these lines are set as points needed to create the surface.

Next, Figure 2(2) illustrates the process for measuring the angles of corners when there are two or more roads in contact with the site and two of them are in contact with one corner. Firstly, points containing corners to be subjected to setback was selected, and lines were created by connecting the points. The angle vector between the lines generated was then measured to determine if the angle is less than 90 degrees or between 90 and 120 degrees. If the angle falls within the specified range, the value for setback was determined. Since there were three possible setback values (2/3/4 m from the corner), conditions were checked for compliance, and the start and end points of the setback lines were set as points.

After going through the process in Figure 2(2), the points created by the process so far were connected to create the building boundary, and this was used to generate a surface, enabling the calculation of the maximum floor area available for creating masses. Separately, the number of parking spaces was determined, with additional variables set to account for the maximum number of parking spaces that could be added within the site area, beyond the minimum required by local ordinance and including the width of the parking lanes.

Once the parking spaces were configured, as shown in Figure 2(3), the parameters for the outputs to be constructed within the site were set (rotation, length along the X-axis, length along the Y-axis, and number of floors) and the outputs were set to be generated in GD based on this process. The final output was derived from the masses generated through the process so far, considering the suitability of coverage ratio and floor area ratio based on usage, and the final coverage ratio and floor area ratio were outputted. This type of algorithm, implemented within Dynamo's GD script, allowed for the selection of fixed variables and one of four output methods (Optimized, Randomized, Spaced Evenly, and Like This), enabling the generation of outputs based on the chosen quantity.

4. Case Study

4.1. Select the Actual Sites

To test the proposed algorithm's suitability for actual site use, this paper focused on sites within the quasi-residential area of Jung-gu, Daegu. Additionally, to ensure the accuracy of the algorithm, it was decided to conduct simulations with two case studies: one involving an old building and the other involving a newly constructed building. Based on this, the buildings were chosen to simulate in this study.

The representative addresses for each case were 307-16 Jungang-daero, Jung-gu, Daegu (A) and 46, 418 gil Dadgubal-daero, Jung-gu, Daegu (B). The current status of the land in this area is presented in Table 6. The images at the bottom of Figure 3 depict the Revit site modeling created by extracting only the target site and adjacent sites from the CAD file (dxf) of Jung-gu, Daegu provided by the National Geographic Information Institute.

Table 6. Information on Case Studies.

Category	Status (A)	Status (B)
Usage Area	Quasi-residential Area	Quasi-residential Area
Count of Roads	3	3
Degrees of Edges	West side: 90° East side: 89°	West side: 90° East side: 97°
Status of Area Opposite	General Buildings	Public Institution (Daegu Dongbu Office of Education)
Widths of Roads	West side: 5.3 m South side: 5.4 m East side: 8.9 m	North side: 1.5 m West side: 0.8 m East side: 9.8 m

From DXF files provided by Korean National Geographic Information Institute [29].

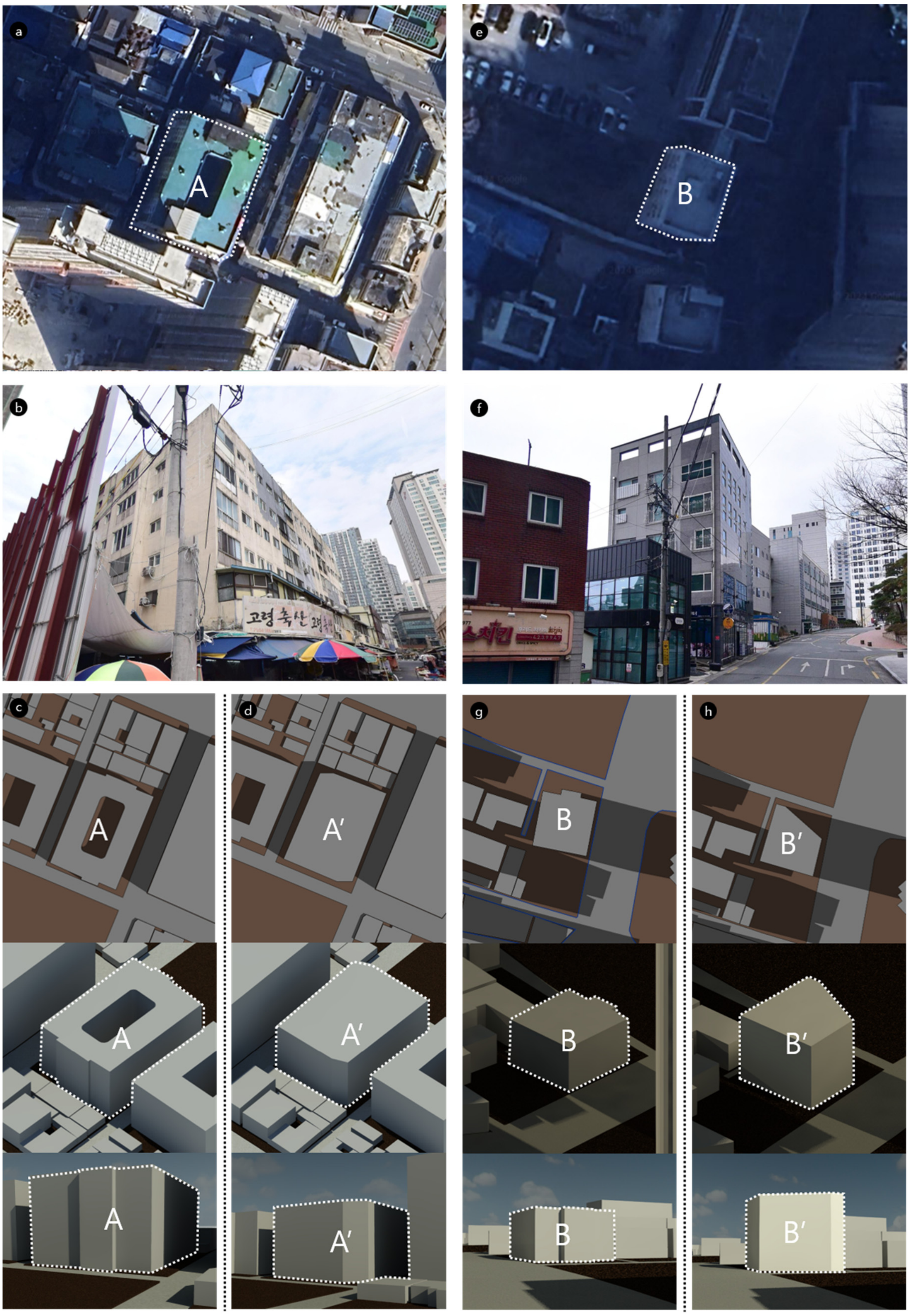

Figure 3. Case Studies A and B. The left ones are located at 307-16 Jungang-daero in Jung-gu, Daegu and the right ones are located at 46,418 gil Dalgubal-daero in Jung-gu, Daegu. This figure includes the status of the target building (**a**,**b**,**e**,**f**) and Revit original modeling of those (**c**,**g**) and the output of the algorithm (**d**,**h**).

The conditions for creating the site model were as follows:

- The site radius was set to form a square with dimensions of 90 × 120 m (east–west, north–south) centered on the representative address.
- The adjacent site boundary lines were based on GIS files (Shx) provided by the National Geographic Information Institute and attached to the Revit modeling.
- When creating the Toposolid model, the CAD file (dxf) mentioned above serves as the reference, with the site and road elements distinguished using Sub-divide.

After the algorithm completes the output process with GD, the result value (A number of outputs) and output method were set so that the outputs emerge. The process involved the selection of the outputs most similar to the real buildings and a comparative analysis between the selected output and the real buildings.

4.2. Discussion of Case Studies

The results of the algorithm simulation on actual site modeling in this study were as follows:

- Firstly, the setback line from the road boundary only operated when it was less than 4 m, ensuring that there was no setback line for buildings on roads wider than 4 m. Additionally, in the case of corner angles, the algorithm was designed to apply only on the side not adjacent to the 8 m road, enabling the designation of building lines according to the angle.
- Considering that the building was designed earlier than the parking law, nodes such as "If" and "Boolean" were used to determine the installation of parking spaces.
- When running the generative design (GD), comparing the actual building on the site with the most similar output from the algorithm showed many similarities in mass form, such as the coverage ratio, floor area ratio, and number of floors, excluding detailed features like courtyards.

While several possibilities emerged from the proposed algorithm, there were also areas for improvement and limitations:

- Since the algorithm did not autonomously interpret and apply codes but requires manual manipulation of scripts by users, there is still a need to consider avenues for the program to self-adjust.
- In cases where users may not obtain the desired output despite setting many outputs, adjustments in unit size and setting the GD output method to "optimized" should be considered for follow-up research.
- Since this study focused on a relatively narrow scope, namely "neighborhood facilities in semi-residential areas", the follow-up research should consider broadening the scope.
- The outputs of the algorithm are monotonous, as all the layers of output have the same shape. Therefore, the algorithm should go through the process of generating other shapes of each floor in accordance with the codes.
- In this case study, there were only two studies, and they are located close to each other within approximately 100 m. Thus, the number of studies should be increased and conducted in various regions in Korea (because this study is based on Korean Building Codes).

5. Conclusions

This study aimed to reduce time and costs through the use of a 'building code checking' algorithm developed from this research in the process of reviewing building codes that must be performed in the schematic design. In addition, this study built an algorithm based on the way humans interpret building codes, allowing computers or programs to interpret building codes the way humans do. Based on the analysis results using the algorithm, an optimized architectural model corresponding to pre-design or schematic design could be created.

Additionally, in this study, the automated code checking algorithm proposed was applied to analyze the site model and apply the codes autonomously. Furthermore, by setting multiple variables for open spaces such as parking spaces, outputs were generated, and the optimal solution that meets the coverage ratio and floor area ratio criteria was derived. This process emphasizes the significance of efficiently performing the most crucial and time-consuming aspect of architectural planning—proposing building masses compliant with building codes—using a program. However, there are still algorithm and case study limitations. First, it is necessary to find a way to apply it to buildings other than neighborhood living facilities. Additionally, the scope of case studies needs to be expanded further since the case studies were limited to Jung-gu, Daegu. This study still requires manual input by humans to build the algorithm, so future studies should include automation measures. Last, the shape of the output is monotonous, so a more diverse form is needed.

In follow-up studies, we plan to explore incorporating additional legal information, local ordinances, and provisions related to district-level plans into the algorithm developed in this study. If such follow-up research is conducted, it is expected to enable more efficient generation of architectural plans compliant with building codes during the planning phase.

Author Contributions: Conceptualization, S.S.; Methodology, S.J. and S.S.; Writing—original draft, S.J. and S.S.; Writing—review & editing, S.S.; Funding acquisition, S.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Research Foundation of Korea, grant number "NRF-2022R1F1A1073308" and supported by the Bisa Research Grant of Keimyung University in "20230187".

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding authors.

Conflicts of Interest: The authors declare no conflict of interest. The sponsors had no role in the design, execution, interpretation, or writing of the study.

References

1. Kim, I.H.; Choi, J.S.; Lee, S.J. The Introduction of open BIM-based Building Code Compliance Checking System. *BIM* **2020**, *22*, 35–38.
2. Miles, D. What Is Generative Design, and How Can It Be Used in Manufacturing. Redshift by AUTODESK. 2022. Available online: https://www.autodesk.com/kr/design-make/articles/what-is-generative-design-kr (accessed on 8 June 2023).
3. Seo, J.C.; Kim, H.J.; Kim, I.H. Open BIM-Based Quality Control for Enhancing the Design Quality in the Architectural Design Phase. *J. Korea Inst. Constr. Eng. Manag.* **2012**, *13*, 3–15.
4. Kim, Y.R.; Lee, S.H.; Park, S.H. Development of Rule-Set Definition for Architectural Design Code Checking based on BIM-for Act on the Promotion and Guarantee of Access for the Disabled, the Aged, and Pregnant Women to Facilities and Information. *J. Korea Inst. Constr. Eng. Manag.* **2012**, *13*, 143–152.
5. Park, C.Y.; Jang, H.I.; Lee, D.G.; Kim, K.S. Trends in environmental building regulations and introduction of automated review programs. *Korean Inst. Archit. Sustain. Environ. Build. Syst.* **2018**, *12*, 33–40.
6. Kim, I.H.; Lee, S.J.; Choi, J.S. Proposal of Development and Application of the Buildings by Use Classification System for openBIM-based Automatic Rule Checking. *J. Soc. Comput. Des. Eng.* **2021**, *26*, 408–417. [CrossRef]
7. Eastman, C.M. The Use of Computers Instead of Drawings. *AIA J.* **1975**, *63*, 46–50.
8. Ministry of Land, Transport and Maritime Affairs. *BIM Application Guide in Architecture*; Ministry of Land, Transport and Maritime Affairs: Sejong, Republic of Korea, 2010.
9. Autodesk Building Solutions. Building Information Modeling in Practice. AUTODESK. 2003. Available online: https://images.autodesk.com/apac_grtrchina_main/files/aec_bim.pdf (accessed on 4 April 2024).
10. Yoon, Y.J.; Kim, D.H. A Study on the Organizational Change in Architectural Design Firm by Introducing BIM. *J. Archit. Inst. Korea Plan. Des.* **2008**, *24*, 11–18.
11. Lee, K.I.; Park, J.J.; Choi, H.R.; Shin, M.H. A Study on the Development of BIM based Railway Infrastructure Information Management System for the Analysis of BIM Applications in Government and Public Agencies. *KIBIM Mag.* **2018**, *8*, 1–14.
12. Kim, J.D. Archi & law-The Ideology & Interpretation Principle orjf the Building Code. *J. Archit. Inst. Korea* **2017**, *577*, 152–163.
13. Ministry of Land, Infrastructure and Transport. *The Guideline of Architectural Administrative*; Ministry of Land, Infrastructure and Transport: Sejong, Republic of Korea, 2013.
14. You, K.H.; Jin, H.Y. A Fundamental Study for the Amendment of Architecture Law. *Notre Dame L. Rev.* **2010**, *2010-5*, 1–203.

15. Kim, I.H. Open BIM (IFC-BIM) at GSA. *BIM* **2008**, *08*, 53–55.
16. CORENET e-PlanCheck. Singapore's Automated Code Checking System—AECbytes. 2005. Available online: https://www.aecbytes.com/feature/2005/CORENETePlanCheck.html (accessed on 25 May 2023).
17. Lee, S.H. Automated-Baesd Building Code Checking System. *J. Korea Acad. Ind. Coop. Soc.* **2006**, *7*, 420–430.
18. Kim, I.H.; Kim, H.S.; Choi, J.S. A Methodology for Design Quality Control of Super-tall Buildings based on BIM: Focused on Quality Control for Evacuation Check. *J. Archit. Inst. Korea* **2012**, *28*, 57–64.
19. Cho, S.K.; Kim, S.S. Study on the Efficient Response to Architectural Civil Complaints Using Large Language Models (LLM). *auri* **2023**, *2023-6*, 1–72.
20. Lee, D.K. Announcement of the Development Performance of ChatGPT Construction Law Interpretations System. Kharn. 2023. Available online: http://www.kharn.kr/news/article.html?no=24000 (accessed on 21 May 2024).
21. Lee, J.W. The AI explaining itself: 'Generative AI' and 'Artificial General Intelligence'. *Forbes Korea*, 23 February 2023; pp. 70–72.
22. Cho, D.K.; Lee, J.K. Training Floorplan Sketches and Applying to the Spatial Design-Focused on the Development of Automated BIM Modeling module from Floor Plan Sketches in the Early Stage of Design. *J. Korea Inst. Spat. Des.* **2021**, *16*, 365–374.
23. Mosser, L.; Dubrule, O.; Blunt, M.J. Reconstruction of three-dimensional porous media using generative adversarial neural networks. *Phys. Rev. E* **2017**, *96*, 043309. [CrossRef] [PubMed]
24. Shim, Y.J.; Jin, K.N.; Kwon, S.M.; Seo, H.J.; Kim, Y.J. AI Based Construction Technology and Research Strategy. *Land and Housing Research Institute*. 2020. Available online: https://www.codil.or.kr/viewDtlConRpt.do?gubun=rpt&pMetaCode=OTKCRK200197 (accessed on 9 September 2023).
25. Hwang, E.K.; Kim, S.A.; Yoon, H.J.; Park, S.R. Improvement for Classification System of Building Use on Building. *KICT*. 2014. Available online: https://www.auri.re.kr/gallery.es?mid=a10303000000&bid=0011&b_list=10&act=view&list_no=1644&nPage=1&vlist_no_npage=0&keyField=&orderby= (accessed on 3 April 2024).
26. Enforcement Decree of the National Land Planning and Utilization Act. Article 76. The Limitation of Buildings in Special-Purpose Area. Available online: https://www.law.go.kr/%EB%B2%95%EB%A0%B9/%EA%B5%AD%ED%86%A0%EC%9D%98%20%EA%B3%84%ED%9A%8D%20%EB%B0%8F%20%EC%9D%B4%EC%9A%A9%EC%97%90%20%EA%B4%80%ED%95%9C%20%EB%B2%95%EB%A5%A0/%EC%A0%9C76%EC%A1%B0 (accessed on 3 September 2023).
27. Ministry of Land, Infrastructure and Transport. Available online: https://www.molit.go.kr/USR/NEWS/m_71/dtl.jsp?lcmspage=1&id=95087983 (accessed on 7 March 2024).
28. DATA PORTAL. The Special-Purpose Areas in Daegu. 2022. Available online: https://www.data.go.kr/data/15005378/fileData.do?recommendDataYn=Y (accessed on 21 October 2023).
29. Korean National Geographic Information Institute. Available online: https://map.ngii.go.kr/ms/map/NlipMap.do (accessed on 31 March 2024).