ICCEPM 2024 https://dx.doi.org/10.6106/ICCEPM.2024.0070
The 10th International Conference on Construction Engineering and Project Management
Jul. 29-Aug.1, 2024, Sapporo

Shape Grammar-Driven BIM Model Database for a Modular Building Design Recommender System

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Abstract: The absence of standardized architectural design configurations poses significant challenges in stakeholder collaboration during the pre-design phase, particularly for modular buildings. Clients often lack comprehensive knowledge of potential design configurations for their proposed buildings, leading to dissatisfaction upon project completion. This issue is exacerbated in office buildings where floor plan layouts are uncertain due to diverse employee needs. To address these challenges, this research introduces a BIM-based dataset for modular office buildings using shape grammar principles. The research manipulates the location of core modules (including staircases, elevator shafts, and entrances) based on shape grammar principles, resulting in twenty unique configurations that provide standardized options for BIM model development. The initial phase involves developing a naming convention based on shape grammar principles to determine the core module locations. Using this convention, BIM models for modular office buildings are created, forming a database connected to the frontend and backend of a recommender system. This system recommends three different design options to clients based on their specific needs, fostering improved collaboration in the pre-design phase by involving clients directly. The user interface of the recommender system aids clients in understanding potential office building configurations, thereby enhancing collaboration and decision-making. Through the amalgamation of shape grammar principles and BIM technology, this proposed system offers a promising approach to advancing efficiency and precision in architectural design communication and representation.

Key words: Architectural Design, BIM (Building information Modeling), Modular building, Shape Grammar, Naming Convention.

1. INTRODUCTION AND BACKGROUND

The Architecture, Engineering, and Construction (AEC) industry's complexity and collaborative requirements underscore the need for cohesive teamwork among clients, architects, engineers, and construction professionals. This intricate nature of collaboration introduces various challenges in project design and construction [1], including issues such as ineffective communication, divergent stakeholder priorities, and difficulties in information management [2]. These challenges can impede the collaborative efforts of clients and project teams. For instance, representing building designs accurately and comprehensively presents two major challenges: handling heterogeneous data sources from architecture, engineering, and interior design, and addressing the dynamic evolution of designs to meet the client's evolving needs. Efficient communication is essential for achieving clear project understanding, fostering collaboration, facilitating effective problem-solving, and ultimately achieving successful architectural outcomes [3]. Effectively communicating the floor plan layout configuration to the client is a paramount element in design collaboration during the initial design phase. For instance, in modular construction, where the design is tailored for both manufacturing and assembly phases, accurate communication of the initial design and building layout to the client is crucial. Failure to do so may lead to design modifications that significantly impact on the manufacturing phase, potentially causing project delays or cost escalations. Most often, architects design the floor plan layout based on their expertise in the field, anticipating minimal changes from the client on some occasions. However, diverse clients with varied needs, and different project types, such as offices and residential buildings, exhibit distinct layout requirements. When it comes to core modules and entrances in modular office buildings, the design must be flexible and customizable, comfortable, durable, aesthetically-pleasing, sustainable, and accessible. The use of modular designs in the office offers unique spaces and features that can adjust to meet the changing dynamics of the workplace.

BIM significantly streamlines design processes by serving as a centralized repository for project information, promoting collaboration, and enabling design analysis and optimization [4]. Developing a BIM based framework can improve design configuration efficiency, communication, and collaboration. However, BIM alone cannot address the client needs for floor plan configuration. To address these issues, a framework or a system that provides a structured representation of office building design details is required. Integrating BIM with shape grammar to create a system that represents the configuration of floor plans can improve communication and make it easier to address client needs in the plans in a seamless manner. Integrating BIM with information technology can further improve the collaboration among project stakeholders [5,6]. However, this process model of enhancing project productivity through effective communication is yet to be studied. A predefined and agreed-upon BIM based naming convention and standard is a condition without which the project could not succeed [7,8]. Applying these standards to directories, files, parameters, and any element shared among the stakeholders will guarantee fewer misunderstandings and errors when exchanging data.

Shape grammar, developed by Stiny and Gips [9], serves as a computational formalism for generating geometric shapes. Functioning as a design generation method, shape grammar executes rules to create designs, offering an efficient approach for automation in architectural design. In architecture, it is a method that generates architectural shapes and spatial configurations using predefined rules and operations, extensively researched, and applied in various projects [10]. For instance, GPLAN, a software dedicated to constructing dimensioned floorplan layouts, utilizes graph-theoretical and optimization techniques [11]. It takes user requirements in two forms: Adjacency graph and Dimensionless layout. GPLAN then generates dimensioned floorplans based on the provided adjacencies. In the realm of BIM, this approach suggests that each distinct floor plan layout, defined by a specific set of shape rules, could be assigned a unique identifier. Such an identification system would facilitate easier referencing, tracking, and modification of floor plans within a BIM system. However, it is essential to recognize that implementing such a system demands careful consideration of factors like the complexity of the shape rules, the diversity of potential floor plan layouts, and the system's flexibility and adaptability to changes in design requirements. Furthermore, the integration of shape grammar with visual coding [12] and reinforcement learning [13] has been employed to create diverse configurations for floor plan layouts. Additionally, it is noteworthy that research has explored real-time procedural generation of building floor plans [14]. This involves developing algorithms capable of generating floor plans resembling those created by architects, with potential for further refinement and adjustment. Integration of such algorithms into a BIM system could automate the assignment of unique identifiers to each generated floor plan.

This paper aims to create a modular office building dataset for an office recommender system, featuring diverse configurations to enhance communication with clients during the initial design phase. The research scope encompasses the adoption of shape grammar principles for floor plan layout development, the creation of a BIM model dataset, and its integration into the recommender system. This article is structured as follows: Section 2 outlines the methodology which covers the development of the naming conventions, and its application in BIM, Section 3 depicts BIM dataset integration into a recommender system and finally, Section 6 presents the conclusion and provide few future recommendations.

2. RESEARCH DESIGN AND EXCUTION

Figure 1 illustrates the research methodology employed to establish a BIM database based on shape grammar principles for recommender system. The subsequent sections will provide a concise elaboration on how this methodology has been implemented to fulfill the objectives of this paper.

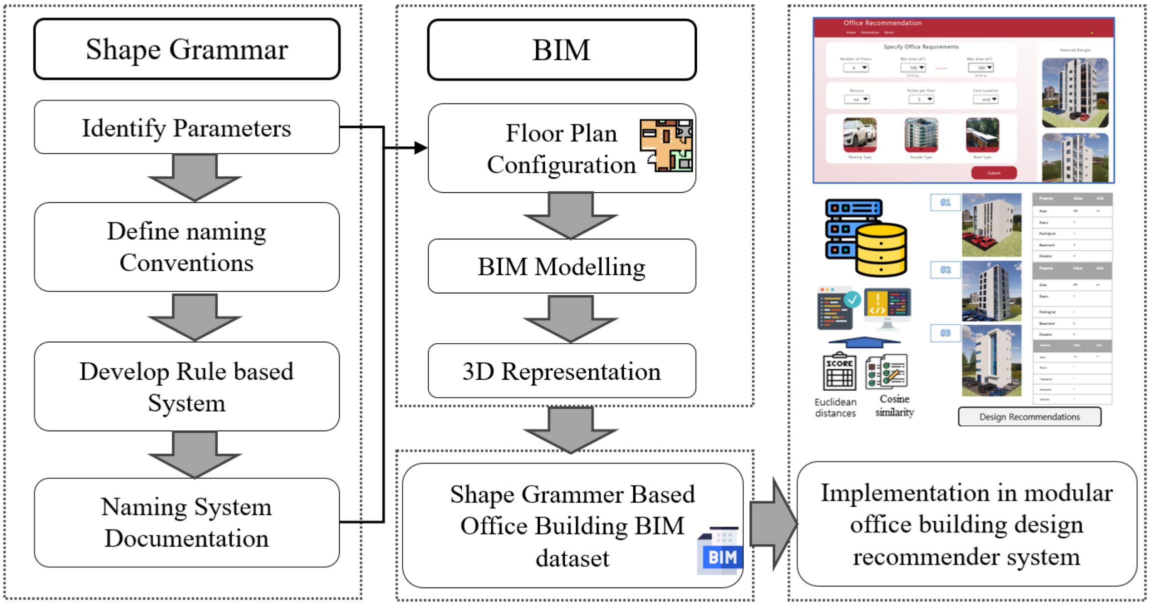

Fig. 1 Research Flow chart

2.1 Systematic naming convention development

The naming convention developed for modular office buildings comprises various modules to formulate both individual floor plans and the entire model. Specifically, modules containing stairs and an elevator are identified as core modules. The location of these core modules, along with the main entrance to the building, serves as parameters for the application of shape grammar principles, resulting in unique configurations. The initial assumption is a rectangular layout for the building, as illustrated in Figure 2. The shape grammar principles used in the floor plan layout configuration are 1) Symmetry and Asymmetry, 2) Proximity and Accessibility, 3) Orientation and view, 4) Modularity and repetition, 5) user-centered design, and 6) flexibility in configuration.

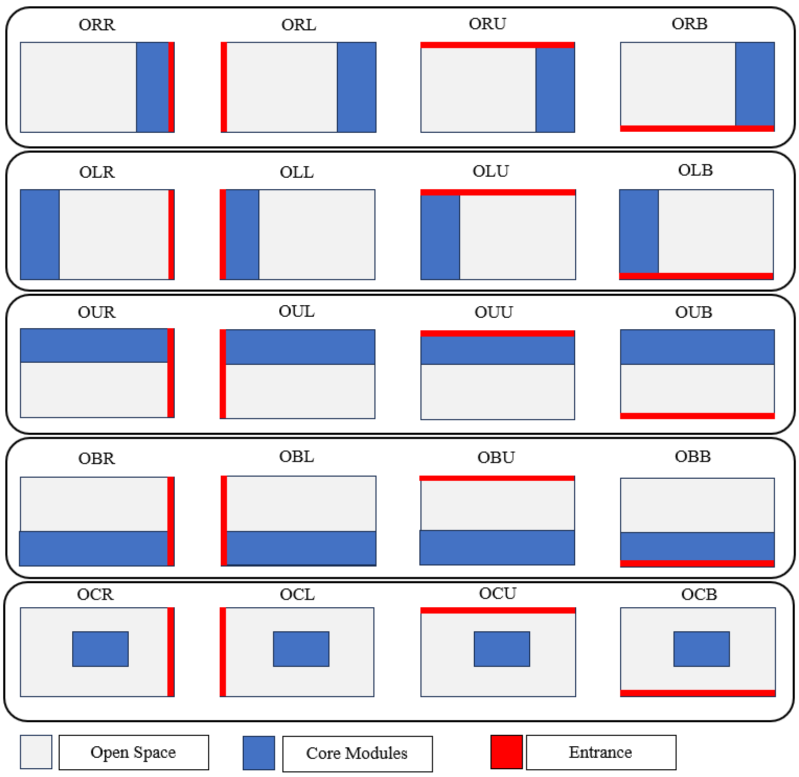

Fig. 2 Core modules configuration based on shape grammar principles

Applying shape grammar principles led to the creation of 20 distinctive floor plan configurations. Each configuration is assigned a unique identifier based on its core module location, represented by a three-letter code. The first letter, "O," consistently denotes an office, while the second and third letters signify the direction of core module and main entrance placement—R (Right), L (Left), U (Upper), B (Bottom), and C (Center). Table 1 shows the unique three letter code generated using the shape grammar principles and Figure 2 shows its corresponding typical configuration.

Table 1: Unique three letters codes generated for office buildings layout using naming systems

No.	Code	Description
1	ORR	Office with Core Modules on the Right, Entrance on the Right
2	ORL	Office with Core Modules on the Right, Entrance on the Left
3	ORU	Office with Core Modules on the Right, Entrance on the Top
4	ORB	Office with Core Modules on the Right, Entrance at the Bottom
5	OLL	Office with Core Modules on the Left, Entrance on the Left
6	OLR	Office with Core Modules on the Left, Entrance on the Right
7	OLU	Office with Core Modules on the Left, Entrance on the Top
8	OLB	Office with Core Modules on the Left, Entrance at the Bottom
9	OUR	Office with Core Modules on Upside, Entrance on the Right
10	OUL	Office with Core Modules on Upside, Entrance on the Left
11	OUB	Office with Core Modules on Upside, Entrance on the Bottom
12	OUU	Office with Core Modules on Upside, Entrance on the Top
13	OBR	Office with Core Modules at the Bottom, Entrance on the Right
14	OBU	Office with Core Modules at the Bottom, Entrance at the upside
15	OBL	Office with Core Modules at the Bottom, Entrance on the Left
16	OBB	Office with Core Modules at the Bottom, Entrance at the Bottom
17	OCL	Office with Core Modules at the Center, Entrance at the Left
18	OCR	Office with Core Modules at the Center, Entrance at the Right
19	OCU	Office with Core Modules at the Center, Entrance at the Upside
20	OCB	Office with Core Modules at the Center, Entrance at the Bottom

The three-letter unique identifier is combined with additional parameters, including design number, building configuration mirroring, and rotation. Rules are established for mirroring and rotation operations. Mirroring options include horizontal (MH), vertical (MV), or simultaneous horizontal and vertical mirroring (MX). Rotation, limited to 90-degree increments in the clockwise direction, is represented by Rx, R1, R2, and R3, corresponding to 0, 90, 180, and 270 degrees, respectively. Figure 3 showcases the final naming convention demonstrating the integration of shape grammar principles and parameters into a coherent and systematic approach for uniquely identifying and categorizing diverse floor plan configurations within the modular office building. Table 2 depicts the naming conventions developed for floor plan with core module to the Right and with different entrance directions.

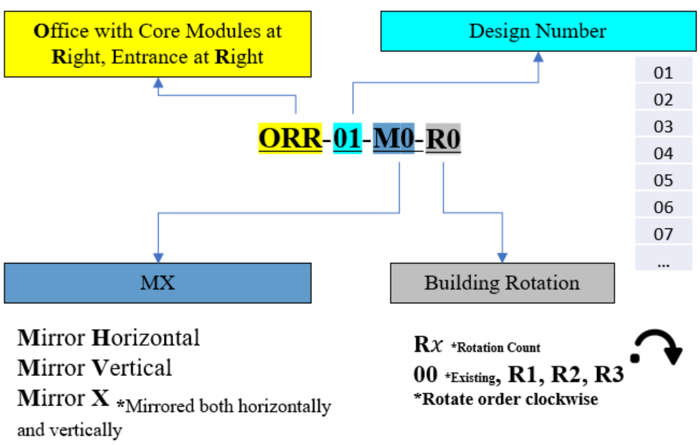

Fig. 3 Final naming convention for office building configuration

Table 2: BIM models attributes corresponding to unique ID generated through naming convention

Unique ID	Land area (sq.m)	Floor area (sq.m)	Number of floors	Gross floor area (sq.m)
ORR-01-M0-00	630	366	12	4386
ORL-01-M0-00	507	327	9	2940
ORU-01-M0-00	455	305	8	2444
ORB-01-M0-00	255	126	7	880

2.2 Application in BIM models

The 20 unique office building configurations were translated into BIM models using Autodesk Revit, resulting in diverse floor plan layouts with varying building shapes and areas, as depicted in Figure 4. These BIM models serve as templates for generating new office building configurations. The naming convention, reflecting core module locations in an easily understandable format, facilitates clear communication among project stakeholders, including the client. This system ensures the seamless incorporation of client needs into the templates. The BIM models are exported to IFC files to create a dataset of office building models which will be used in recommendation system in future.

The BIM modeling incorporates modular properties in its configuration and 3D modeling, dividing the model into different modules of sizes (3x9) m and (3x6) m. Core modules, including the staircase, elevator shaft, and entrance, are identified, and their locations are determined using naming conventions. Once a standard configuration is established for a specific area, it can be extended to different area sizes by adding extra modules to one side of the floor plan. This configuration allows for easy fulfillment of the client's area needs by maintaining the same core module locations despite the addition of extra modules.

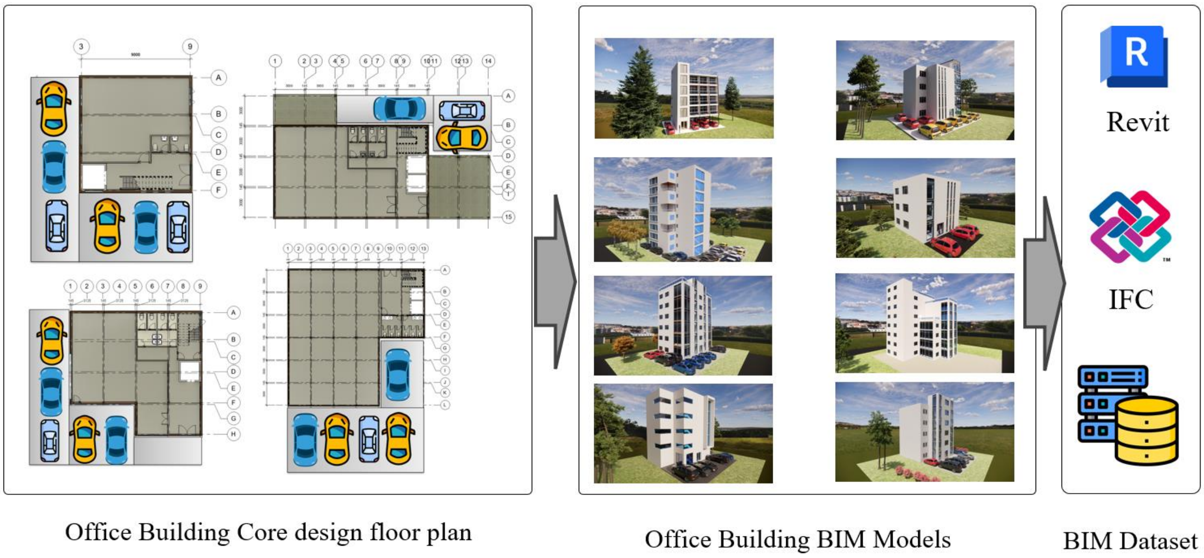

Fig. 4 BIM dataset development

3. BIM DATASET UTILIZATION IN RECOMMENDER SYSTEM

The naming convention operates within the BIM database of the recommender system, assigning a unique ID to each BIM model. This unique identifier serves as a representation of the configuration of the BIM model. The use of a unique ID facilitates seamless comparison with the specific requirements of the client, streamlining the recommendation process. Users input their building configuration preferences, and these input values are compared with the BIM database utilizing cosine and Euclidean similarity functions. These functions rank the top three most suitable models from the BIM database. Users can then view the recommended models in both 2D and 3D on the output page, with rendered views enhancing the realism for a more immersive client experience. Figure 5 shows the process of recommender system for office building design based on client needs.

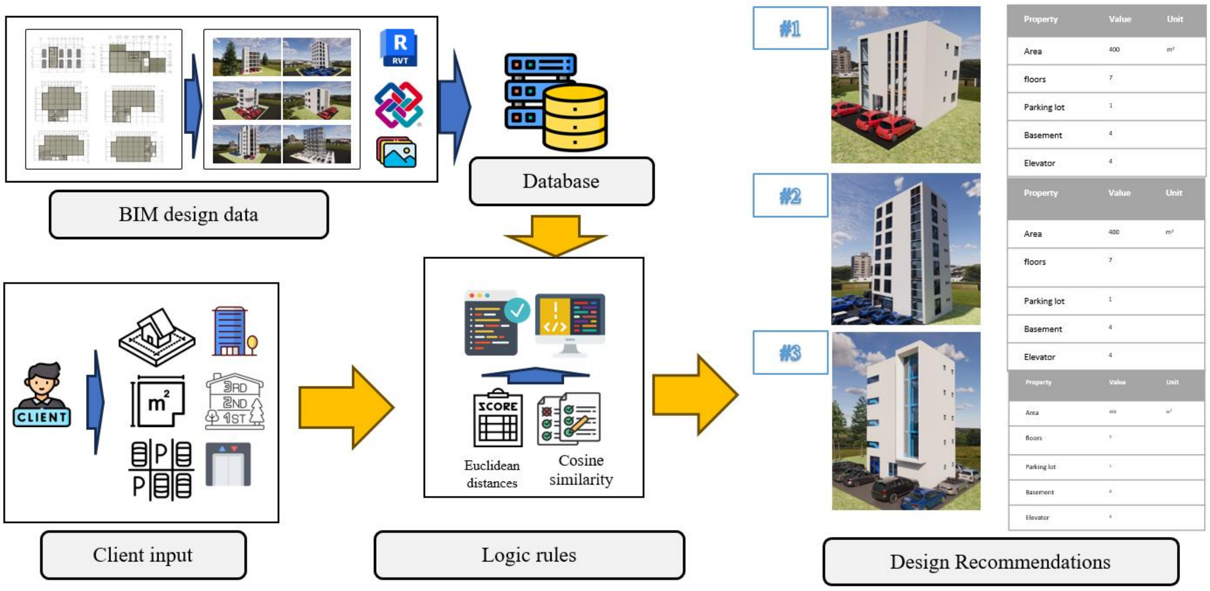

Fig. 5 Process framework of the design recommendation system

Figure 6 shows the user interface for the recommender system in which the client chooses the attributes of building for recommendations. Clients have the flexibility to select various floor plan parameters, including floor area, core module locations, the number of core module locations, the number of floors, and floor area ratio, enabling a tailored and comprehensive customization of their building configurations. It can be seen in the figure that the core module location selection is provided in the user interface which is based on the naming conventions and its value can be automatically determined from the unique ID of the BIM model in the backend.

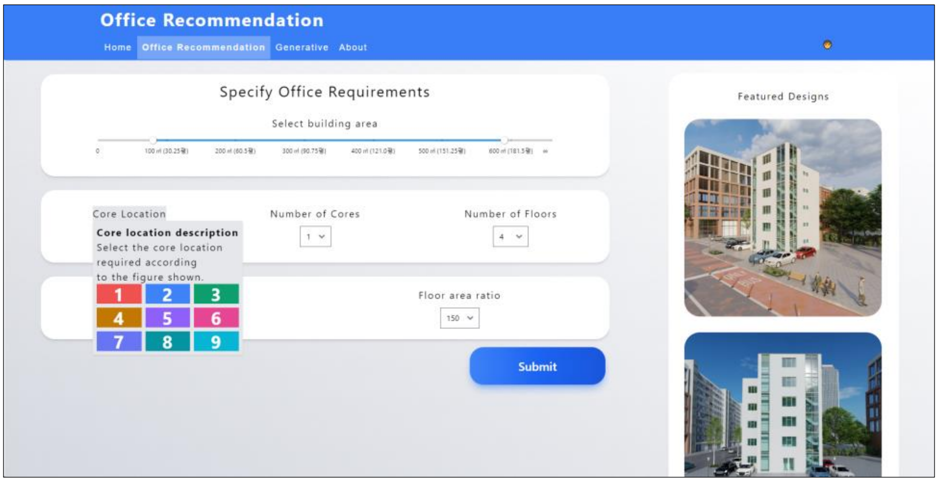

Fig. 6 User interface for the office building recommender system

4. CONCLUSION

This research introduced a BIM-based dataset for modular office buildings using shape grammar principles to manipulate core module locations, resulting in twenty unique configurations. It employs a naming convention based on shape grammar to guide the placement of modules, creating BIM models connected to a recommender system. This system suggests three design options, involving clients directly and enhancing collaboration in the pre-design phase. The developed naming conventions uniquely represent office building floor plan layouts, allowing the creation of distinct IDs for different design configurations. This system is particularly effective for handling big data and large data sets of office buildings. Additionally, it facilitates easy identification of specific models based on client requirements for core module locations, reducing miscommunication between designers and clients. Furthermore, the unique BIM models can serve as templates for developing new office building configurations. The recommender system helps in enhancing the collaboration of client in the predesign phase which reduces any possible design changes in the future of project execution.

Besides the many contributions and advantages of the BIM dataset and recommender system, there is still more research needed to be carried out. For example, the dataset use for recommender system is not enough to fulfill all the client needs and the recommendation may not match 100% with client needs, so improving the dataset by adding more BIM models can enhance the recommendation system. Moreover, the client needs should be studied through systematic survey to determine what are some needs which the client want in their office building configuration.

ACKNOWLEGEMENTS

This work is supported in 2024 by the Korea Agency for Infrastructure Technology Advancement (KAIA) grant funded by the Ministry of Land, Infrastructure and Transport (Grant RS-2021-KA163269).

REFERENCES

[1] Norouzi, N., Shabak, M., Embi, M. R. B., & Khan, T. H. (2015). The architect, the client and effective communication in architectural design practice. Procedia-Social and Behavioral Sciences, 172, 635-642.

[2] El-Mahdy, D. (2022). Learning by Doing: Integrating Shape Grammar as a Visual Coding Tool in Architectural Curricula. Nexus Network Journal, 24(3), 701-716.

[3] Taleb, H., Ismail, S., Wahab, M. H., & Rani, W. N. M. W. M. (2017, October). Communication management between architects and clients. In AIP Conference Proceedings (Vol. 1891, No. 1). AIP Publishing.

[4] Van Tam, N., Quoc Toan, N., Phong, V. V., & Durdyev, S. (2023). Impact of BIM-related factors affecting construction project performance. International Journal of Building Pathology and Adaptation, 41(2), 454-475.

[5] Boujaoudeh Khoury, K. (2019). Effective communication processes for building design, construction, and management. Buildings, 9(5), 112. https://doi.org/10.3390/buildings9050112

[6] Rehman, S. U., Kim, I., & Choi, J. (2023). Data-driven integration framework for four-dimensional building information modeling simulation in modular construction: a case study approach. Journal of Computational Design and Engineering, 10(6), 2288-2311.

[7] Ajayi, S. O., Oyebiyi, F., & Alaka, H. A. (2023). Facilitating compliance with BIM ISO 19650 naming convention through automation. Journal of Engineering, Design and Technology, 21(1), 108-129.

[8] A Simple BIM Naming Convention Based on ISO 19650 Part 1 - BIMicon. (2024, February 1). A Simple BIM Naming Convention Based on ISO 19650 Part 1 - BIMicon. https://www.bimicon.com/bim-naming-convention-based-on-iso19650-part1/

[9] Ruiz-Montiel, M., Boned, J., Gavilanes, J., Jiménez, E., Mandow, L., & PéRez-De-La-Cruz, J. L. (2013). Design with shape grammar and reinforcement learning. Advanced Engineering Informatics, 27(2), 230-245.

[10] Chen, Y. X., Shu, B., & Chang, H. T. (2023). Exploring Architectural Shapes Based on Parametric Shape Grammars: A Case Study of the "Three Lanes and Seven Alleys" Historic District in Fuzhou City, China. Buildings, 13(8), 2063.

[11] Shekhawat, K., Upasani, N., Bisht, S., & Jain, R. (2020). GPLAN: Computer-Generated Dimensioned Floorplans for given Adjacencies. arXiv preprint arXiv:2008.01803.

[12] El-Mahdy, D. (2022). Learning by Doing: Integrating Shape Grammar as a Visual Coding Tool in Architectural Curricula. Nexus Network Journal, 24(3), 701-716.

[13] Ruiz-Montiel, M., Boned, J., Gavilanes, J., Jiménez, E., Mandow, L., & PéRez-De-La-Cruz, J. L. (2013). Design with shape grammar and reinforcement learning. Advanced Engineering Informatics, 27(2), 230-245.

[14] Mirahmadi, M., & Shami, A. (2012). A novel algorithm for real-time procedural generation of building floor plans. arXiv preprint arXiv:1211.5842.