TURNING EMPIRICAL KNOWLEDGE INTO DIGITAL ASSETS

A workflow assisting intern architects in high-rise conceptual design

CHENGYU SUN[1], YILIN LI[2] and YUELI WANG[3]
[1,2,3]Tongji University; Shanghai Key Laboratory of Urban Renewal and Spatial Optimization Technology.
[1]ibund@126.com, 0000-0002-5686-5957
[2]erica175134@gmail.com, 0009-0000-1172-642X
[3]499630837@qq.com, 0009-0009-4903-0909

Abstract. Experienced architects can quickly formulate high-rise conceptual designs that align with both the clients' needs and building codes through estimation and logical deduction. Usually, such empirical knowledge takes architects years of practice to accumulate. This research aims to externalize this empirical knowledge into generative design method, thereby aiding intern architects in quickly gaining the skills needed to conceive high-rise conceptual designs. We have developed a prototype program and a corresponding workflow, which can assist architects in generating and presenting high-rise designs featuring a rectangular plan. Additionally, when architects make adjustments to the building mass, the program can perform some preliminary verification on the new design.

Keywords. High Rise, Conceptual Design, Empirical Knowledge, Design Automation, Knowledge Transmission, Generative Design.

1. Introduction

Due to safety, economy, and cityscape protection factors, clients and urban planning departments have strict design criteria on high-rise buildings. Often during the conceptual design phase, experienced senior architects can quickly formulate feasible solutions through estimation and logical deduction, which is something most intern architects aren't capable of. Therefore, current conceptual design process of high-rise buildings is always led by a senior architect who first determines the basic architectural form and spatial layout. Mid-level and intern architects then work together to create detailed drawings and 3D models to complete the design. This common workflow creates a scenario where intern architects are often too engaged in drawing work to have the opportunity to learn the advanced experiences of senior architects in high-rise conceptual design. This hinders the progress of intern architects in terms of design capability and also obstructs the passing-on of empirical knowledge from senior architects.

This research aims at using generative design to bridge this gap. By translating the

ACCELERATED DESIGN, Proceedings of the 29th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2024, Volume 1, 383-392.

high-rise conceptual design strategies of senior architects into generative rules, this research turns empirical knowledge into digital assets that can be reused to guide intern architects in formulating a feasible design concept independently.

In the following sections, this paper presents a concise review of related studies on generative design and analyses whether these studies are helpful for guiding intern architects. Then, we introduce our generative-design prototype program and a corresponding workflow, which aimed at assisting intern architects in high-rise conceptual design. The prototype is verified through a simulated design practice. The final part of the paper concludes the strengths and limitations of this research and outlines goals for future work.

2. Related Studies

Based on the logic that drives generation, generative design can be categorized into the following three types: rule-based generation, artificial intelligence (AI) algorithm-based generation and integration of rule-based and AI approaches. Rule-based generative design employs predefined design rules and principles as a structured framework to steer the design process. AI algorithm-based generative design leverages the power of artificial intelligence techniques such as genetic algorithms, neural networks, and evolutionary strategies, enabling the system to learn, adapt, and evolve solutions iteratively.

2.1. RULE-BASED GENERATIVE DESIGN

Donath and Lobos (2009) translated building codes and clients' needs into Boolean operation rules that subtracted mass from the original box volume to generate the envelopes of high-rise buildings. The program automatically generated floor/ section/ elevation plans, industry foundation classes (IFC) model and indicator report for each design. Abdullah and Kamara (2013) demonstrated the capability of parametric design in generating a large number of alternatives, with generative rules based primarily on the aesthetics of building form and facade. Yavuz and Celik (2015) employed shape grammar to generate house units, which were then copied and combined according to specific rules to form the design of an entire high-rise residential building. Erhan and Shireen (2017) introduced a methodology that enabled designers to generate design alternatives derived from a base parametric model, facilitating the simultaneous parameter adjustment of multiple solutions by designers.

2.2. AI ALGORITHM-BASED GENERATIVE DESIGN

Rafiq et al. (2003) employed genetic algorithm to optimize both the total building area and structural material cost, determining the optimal structural layout plan for rectangular, frame-structure high-rise buildings. Elnimeiri and Nicknam (2011) employed genetic algorithm generates the final form of the building through multi-objective optimization of energy conservation, structural performance and morphological constraints. Gane and Haymaker (2012) proposed a methodology called Design Scenarios (DSs) to take into account to as many design goals from various stakeholders as possible during the conceptual design phase. The program optimized the weighted average of these goals. As et al. (2018) presented a graphically based automatic learning system to generate conceptual designs. Deep neural networks were trained to evaluate existing house designs, decomposing them into subgraphs to extract semantically rich building blocks, and then merge the blocks into new compositions. Lee et al. (2023) used algorithms to move and scale the several original volumes based on grid points, generating a large number of building site planning alternatives.

2.3. INTEGRATION OF RULE-BASED AND AI APPROACHES

Sydora and Stroulia (2020) introduced a generative design method that utilized a BIM model representing an empty space, a predefined set of furnishings to be placed, and a set of layout rules as input. Through multiple iterations of adjusting furniture placement and rule-checking, the optimization algorithm progressively completed the interior layout. Abrishami et al. (2021) presented a prototype named G-BIM for residential building layout generation. The building model was constraint by several rules such as number of spaces, site boundary and outline dimensions. Leveraging spatial topology, internal space layouts were iteratively adjusted and optimized by genetic algorithm.

2.4. IMPLICATIONS DRAWN FROM PREVIOUS STUDIES

Some rule-based method research expects to directly generate feasible architectural designs by adding abundant constraints. However, in most practices, constraints primarily serve to prevent extreme situations, and most design decision-making still relies on the architect's analysis and judgement. Other rule-based method research first generates multiple design alternatives, and then uses artificial intelligence algorithms to identify the relatively optimized solution. The algorithm would grow more and more complex as the architect increases the number of optimization goals and adjustable parameters. Consequently, existing research has primarily focused on single-objective and bi-objective optimization problems (Ekici et al., 2019), which falls short in aiding intern architects to comprehensively accomplish the design goals.

In recent years, there has been a growing interest in utilizing deep learning for the generation of architectural designs. However, due to the intricacies of the data collection process and challenges in computer image recognition, designs generated by these algorithms are not yet mature enough for practical use. Depending solely on algorithms to generate designs may also hinder the development of design capabilities for intern architects.

Our research suggests that previous research faced limitations in generating designs comparable to those of senior architects, which can be attributed to the omission of “empirical process” and “approximate values” when developing the generative method. Senior architects would use approximate values to estimated the rough volume and layout of the building, and gradually add detail to the design through a certain empirical process. This saves them time and effort when optimizing multiple design goals. We believe that externalizing this empirical knowledge is not only beneficial for intern architects in passing on the experience of the senior architects, but also enhances the efficiency of current high-rise conceptual design process.

3. Methodology

3.1. FIVE STAGE HIGH-RISE CONCEPTUAL DESIGN WORKFLOW

To recreate the senior architects' empirical design process, the design workflow is segmented into five stages, as illustrated in Figure 1. In Stage One, the program receives two key indicators from the architect: gross floor area and height limit of the building. It then immediately estimates sub-indicators for the architect. Number of floors is calculated by dividing height limit by a preset rough floor-height value. Typical floor area is equal to gross floor area divided by number of floors. The area of each core component, such as elevators and staircases, is estimated separately using the formulas provided by TOSPUR Real Estate Consulting Co. Ltd (2016). These sub-indicators will guide the architect in the following design process. In Stage Two, intern architects engage in the primary parametric design process. The program guides them with input hints, and shows them if the design aligns with the building criteria. In Stage Three, the program automatically generates drawings and a model of the designed building. In Stage Four, architects have the freedom to modified the building's mass using the 3D modelling software which they are familiar with. In Stage Five, the program assists architects in evaluating the modified building mass from Stage Four. The program cuts the mass according to the building section designed in Stage Three, generates new floor plan sketches and compares them with the original floor plan. All the generated drawings can be automatically exported to PowerPoint, facilitating the creation of a brief presentation.

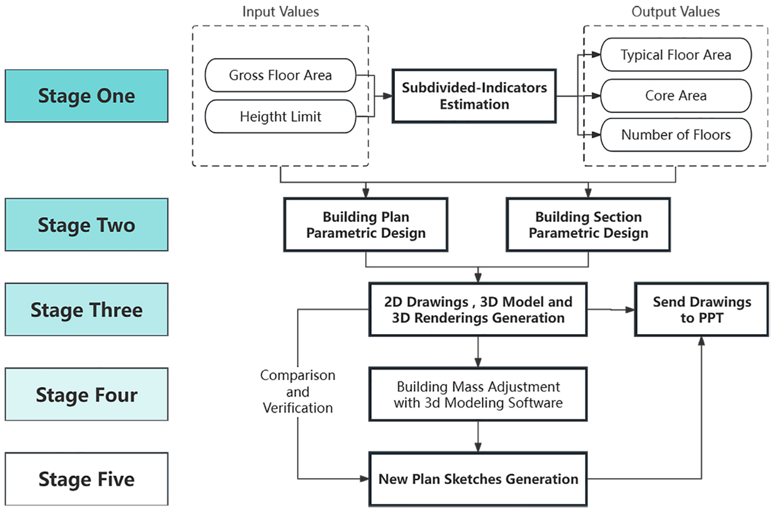

Figure 1. Five Stage High-rise Conceptual Design Workflow

3.2. CONTRIBUTION

3.2.1. Provision of Approximate Values

The program provides plenty of approximate values, which are gathered from literature reviews and research on design institutes in Shanghai, to intern architects through input prompts or predefined options. For instance, in plan parametric design procedure, there are three most commonly used lease span value— 10.5m, 12m, and 13.5m (Mirniazmandan et al., 2018) —for the architects to choose from. However, they are also granted the flexibility to input other values.

3.2.2. Design Check Based on Building Codes

Since intern architects are often not familiar enough with various building codes, they may enter parameters which generate designs violating those codes, for instance, planning only one staircase in a fire compartment. These mistakes are fatal to the design. Once the architect enters wrong parameters, our program will give an instant warning. This not only prevents intern architects from working in vain on invalid designs, but also helps them become familiar with the codes.

3.2.3. Immediate Calculation of Indicators

To ensure both the economic efficiency and safety of the high-rise, design criteria impose strict regulations on numerous building indicators, such as height limit, gross floor area of the building, and so on. During the conceptual design stage, architects dedicate significant effort to adjust the building design, ensuring those indicators comply with the criteria. Usually, these indicators are calculated manually, and an architect has to do lots of recalculation whenever adjustments are made to the design. This scenario not only leads to substantial time wastage, but also diminish the confidence of intern architects. Our research addresses this issue by providing architects with real-time indicator feedback through automated calculations. This enables architects to promptly grasp the outcome of their decisions, empowering them to make adjustments more decisively and efficiently.

3.2.4. Automatic Generation of Drawings and Presentations

In the traditional workflow, architects have to dedicate significant time to manually create drawings and presentations of their designs. In our proposed workflow, once the architect completes parametric design process and clicks "Generate", the program automatically generates plans, sections, axonometric drawings, and renderings of the design. It can also insert these drawings, along with corresponding building information text, into a PowerPoint presentation. This automation alleviates the drafting workload for intern architects, enabling them to invest more time in the creative aspects of design.

4. Prototype

Using two-dimensional drawings to represent architectural designs is still the mainstream in China. Consequently, the prototype program was developed mainly based on the AutoCAD platform. In this section, the prototype would be demonstrated through a simulated design.

According to the design brief, the architect was assigned to design a high-rise building with a height limit of 180 meters and an anticipated gross floor area of 92,000 square meters.

In Stage One, the architect entered 'Gross Floor Area' and 'Height Limit' parameters (highlighted in red in Figure 2), then clicks the 'Run Estimation' button. The program automatically filled in other sub-indicators. The estimated ratio of core area to typical floor area is 21.95%, which falls within the feasible range (Li & Gao, 2020). The program also reminded that according to the building code, current design needed a sprinkler system.

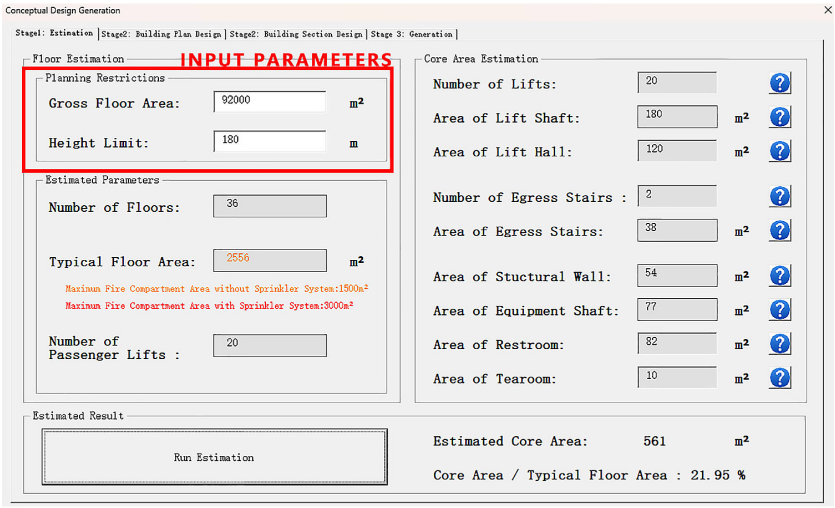

Figure 2. Stage One Interface Demonstration

In Stage Two, the architect adjusted plan and section parameters, as illustrated in Figure 3 and Figure 4. The 'Indicator Check' panel displayed the area deviation between the architect's design and the goal.

To design building plan, the architect adjusted the column grid and the building outline dimension by modifying the column spacing and column number. The "Core Width" was calculated by subtracting twice the "Lease Span" from the "Building Width", ensuring the space between the exterior wall and the core wall was economically efficient for office layout. The upper-right window in Figure 3 provided a preview of the building plan, allowing the architect to know whether some columns were too close to the core before generation of CAD drawings.

As for building-section design, the architect vertically zoned the building by editing the floor list, assigning different floor heights and numbers of floors to different zones.

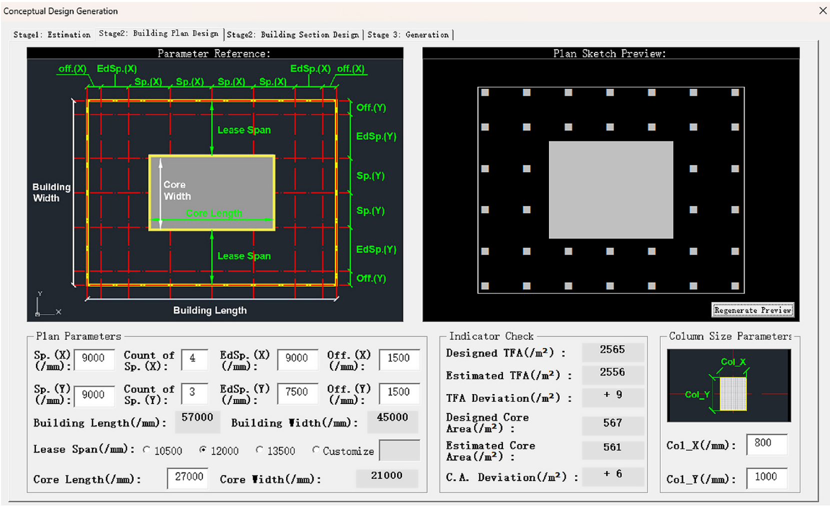

Figure 3. Plan Parametric Design Interface Demonstration

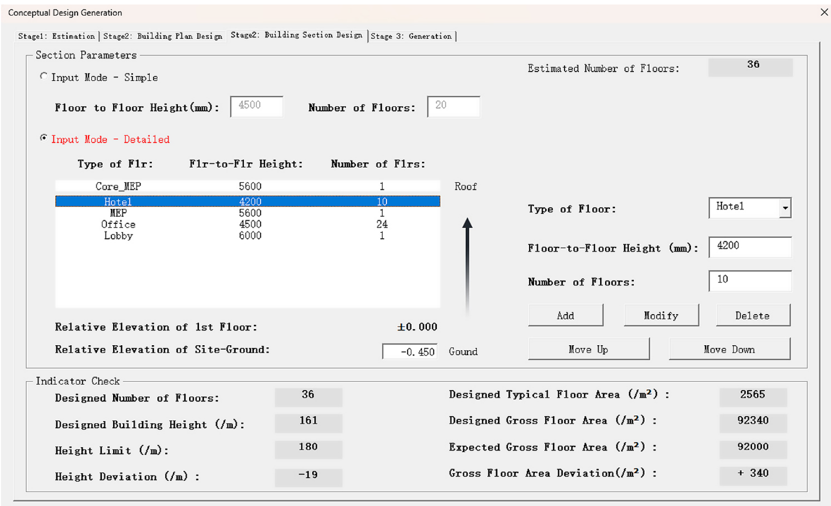

Figure 4. Section Parametric Design Interface Demonstration

With the design of plan and section settled, the architect clicked "Generation", and the program automatically drew various drawings (some of which are shown in Figure 5). The renderings are generated by the POV-Ray engine, using a pre-set site template.

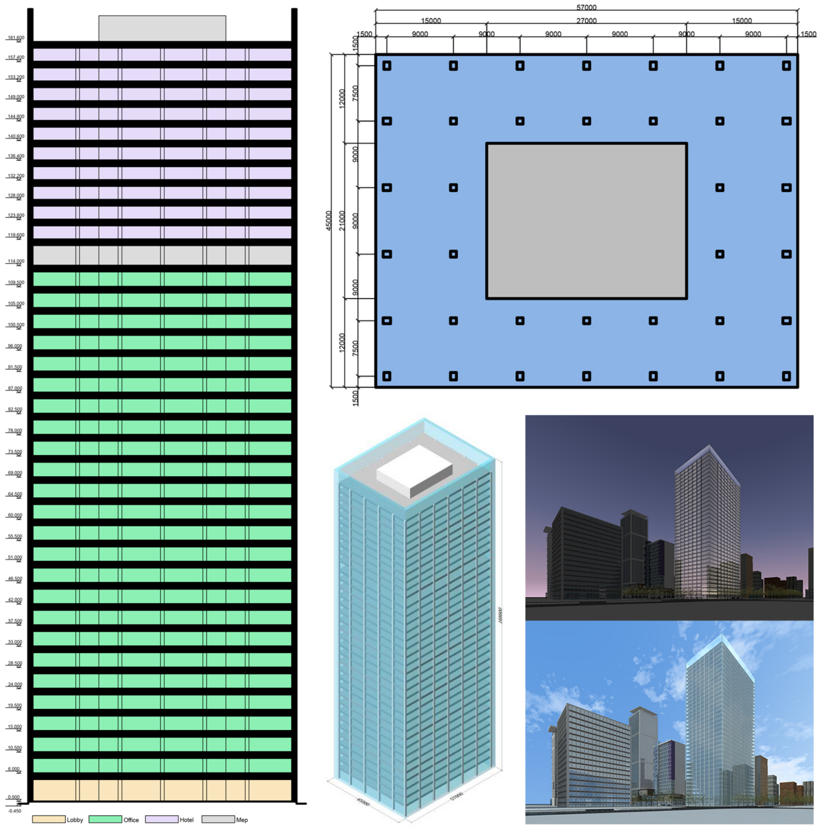

Figure 5. Design Drawings Generated by the Prototype

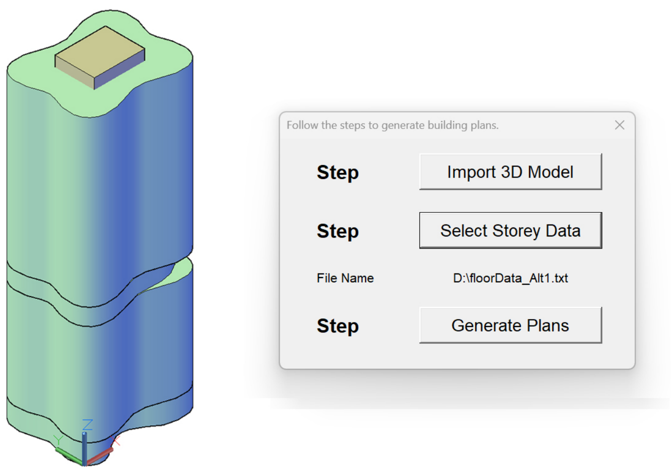

Figure 6. Stage Five Interface Demonstration

In Stage Four, the architect operated on the building's mass using Rhino platform, adjusting the building's outline to a curved shape and making some mass subtraction. The architect then returned to the AutoCAD platform to execute Stage Five. The architect imported the new building mass model into a new CAD drawing, selected the building floor information file of the original design generated in Stage Three, and clicked 'Generate Plans' (see Figure 6). The program generated floor plans of the new mass and compared them with the original structural layout. The area of each floor and the gross floor area were calculated, and the columns that appeared outside of the floor outline were marked out in red (see Figure 7).

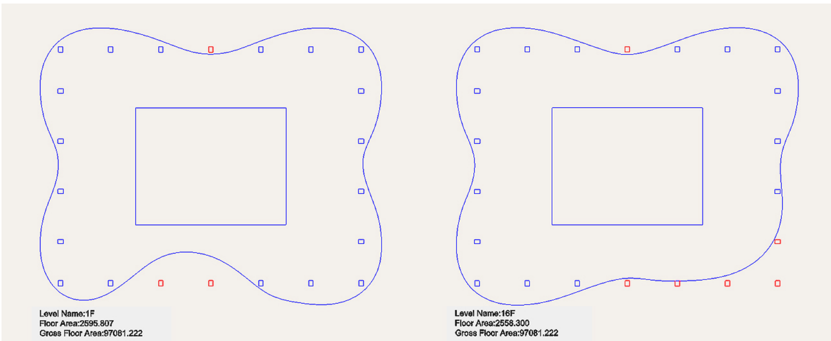

Figure 7. New Plan Sketches Generated in Stage Five

5. Conclusion and Future Work

The senior architects collaborating on this study believed that the prototype can greatly reproduce their usual high-rise-design process. Provision of approximate values, immediate calculation of indicators and quick generation of design drafts spare architects great time when exploring alternatives, enabling intern architects to independently and methodically design high-rises. This proves the feasibility of the prototype in externalizing senior architects' design empirical knowledge.

However, the prototype was mainly developed based on the spatial organization logic of the high-rise building itself, and the site of the building has not yet been taken into account. Also, since the prototype was developed based on the AutoCAD platform, it is mainly good at generating two-dimensional drawings. When architects need to modify the 3D building model, they have to use other modelling software, and there will be information loss during the export and import process.

According to the deficiencies in the above two aspects, future work on the one hand will look for ways to link two-dimensional and three-dimensional building information, and on the other hand, will continue to externalize senior architects' empirical knowledge on high-rise site planning.

Acknowledgements

We would like to express our sincere gratitude to the Shanghai Key Laboratory of Urban Renewal and Spatial Optimization Technology for their generous support and assistance. With their expertise, the research was enabled to explore in-depth the

complex principles of high-rise design.

References

Abdullah, H. K., & Kamara, J. M. (2013). Parametric design procedures: a new approach to generative-form in the conceptual design phase. In *AEI 2013: Building Solutions for Architectural Engineering* (pp. 334-343).

Abrishami, S., Goulding, J., & Rahimian, F. (2021). Generative BIM workspace for AEC conceptual design automation: Prototype development. *Engineering, Construction and Architectural Management,* 28(2), 482-509.

As, I., Pal, S., & Basu, P. (2018). Artificial intelligence in architecture: Generating conceptual design via deep learning. *International Journal of Architectural Computing,* 16(4), 306-327.

Donath, D., & Lobos, D. (2009). Plausibility in early stages of architectural design: a new tool for high-rise residential buildings. *Tsinghua science and technology,* 14(3), 327-332.

Ekici, B., Cubukcuoglu, C., Turrin, M., & Sariyildiz, I. S. (2019). Performative computational architecture using swarm and evolutionary optimisation: A review. *Building and environment, 147,* 356-371.

Elnimeiri, M., & Nicknam, M. (2011, October). A Design Optimization Workflow for Tall Buildings Using Parametric Algorithm. In *Proceedings of the CTBUH 2011 Seoul Conference, Seoul, Korea* (pp. 10-12).

Erhan, H., & Shireen, N. (2017). Juxtaposed designs models: A method for parallel exploration in parametric CAD. In G. Çagdas, M. Özkar, L. F. Gül, & E. Gürer (Eds.), *Future trajectories of computation in design: Proceedings of the 17th International Conference on Computer-Aided Architectural Design Futures (CAAD Futures 2017)* (pp. 402-412). ISBN 978-975-561-482-3.

Gane, V., & Haymaker, J. (2012). Design Scenarios: Enabling transparent parametric design spaces. *Advanced Engineering Informatics,* 26(3), 618-640.

Lee, J., Cho, W., Kim, S., Sohn, D., & Lee, J. (2023). Conceptual design algorithm configuration using generative design techniques. *KIEAE Journal,* 23(1), 5-12.

Li, Y., & Gao, Y. (2020). Chaogaoceng bangong jianzhu biaozhunceng shiyong mianji xishu yanjiu[Study on the floor area ratio of standard floors in super high-rise office buildings]. *Architecture and Culture,* 2020(07), 264-265.

Mirniazmandan, S., Alaghmandan, M., Barazande, F., & Rahimianzarif, E. (2018). Mutual effect of geometric modifications and diagrid structure on structural optimization of tall buildings. *Architectural science review,* 61(6), 371-383.

Rafiq, M. Y., Mathews, J. D., & Bullock, G. N. (2003). Conceptual building design—Evolutionary approach. *Journal of computing in civil engineering,* 17(3), 150-158.

Sydora, C., & Stroulia, E. (2020). Rule-based compliance checking and generative design for building interiors using BIM. *Automation in Construction, 120,* 103368.

TOSPUR Real Estate Consulting Co. Ltd. (2016, June 10). *Chaogaoceng bangong jianzhu hexintong qianxi[A brief analysis of the core of super high-rise office buildings].* Winshang. Retrieved February 15, 2024, from http://file2.winshang.com/file3/2016/6/10/%E8%B5%A2%E5%95%86%E5%85%B1%E4%BA%AB-0113%E8%B6%85%E9%AB%98%E5%B1%82%E5%8A%9E%E5%85%AC%E5%BB%BA%E7%AD%91%E6%A0%B8%E5%BF%83%E7%AD%92%E6%B5%85%E6%9E%9013573394.pdf.

Yavuz, A. O., & Celik, T. (2015). A Rule Based Computer Aided Model Suggestion Developed for Design Process of High-Rise Housing. *Journal of Academic Research,* 7(3), 533.