SIMFORMS

A Web-Based Generative Application Fusing Forms, Metrics, and Visuals for Early-Stage Design

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Abstract. At the current moment when digital technology is gradually spreading, various generative design methods and the rapid iteration of AI models have exceeded public expectations. Nevertheless, in the early stages of architectural design, there are still numerous challenges in connecting forms, metrics, and visuals. When facing conceptual design, designers often need to strike a balance between the visual effects of form and quantitative metrics, lacking an efficient tool to quickly control different design choices and obtain comprehensive feedback. To address this issue, this paper introduces SIMForms, a web-based application aimed at fusing architectural forms, quantitative metrics, and visualization. SIMForms integrates rule-based parametric modelling, metric computation and feedback, along with AI-assisted conceptual image generation. Through SIMForms, designers can generate diverse architectural forms with simple operations in the early design stages, obtaining crucial quantitative metrics and conceptual image as feedback. This multi-module integrated application not only provides a more intuitive and efficient tool for the design process but also offers concept innovation and guidance for designers, driving further development in digital design tools.

Keywords. Early-stage Architectural Design, Web-based Application, Metrics Feedback, Rule-based Modelling, Conceptual Image Generation.

1. Introduction

In the era of rapid advancement in generative design and generative models, the early-stage architectural design process is gradually shifting towards interactive feedback and

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real-time decision-making (Singh and Gu, 2012). For architects and urban designers, diverse inspiration guidance and sufficient data feedback are crucial criteria for evaluating the usability of digital design tools. From another perspective, facing the iterative process of "design test - metric verification", it is crucial to enable architects to quickly obtain architectural form suggestions through basic metric control requirements. This approach serves as a key means to simplify the difficulty of conceptualizing and refining architectural ideas. Therefore, establishing a digital bridge between "architectural form - quantitative metrics - creative visualization" is a practical challenge for the design process.

Rule-based parametric modelling is the most direct and fundamental way to connect architectural style prototypes with quantitative metrics. It has been extensively explored in interdisciplinary fields such as urban procedural modelling (Parish and Müller, 2001). By analysing architectural style prototypes and design logics, multiple architectural forms can be rapidly generated through the definition of algorithms and parameters, providing creative inspiration references (Lee et al., 2014). In recent times, with the widespread enthusiasm for AI large models, discussions on architecture generation and conceptual design based on image generation have gained significant attention (Ploennigs and Berger, 2023). Generating conceptual images that match architectural representation effects based on text prompts or images has become a potential development direction (Albaghajati et al., 2023; Cheng et al., 2023). An early-stage design platform incorporating different modules is a crucial solution for advancing the integration of digital design resources and addressing practical issues.

For integrated design-assist applications described above, user-friendliness has been a significant concern in recent years. This allows designers to obtain generated model or analysis results without the need to master complex algorithmic principles. Some application-oriented research has opted for local software or plugins (He and Yang, 2019; Fink and Koenig, 2019; Song et al., 2023). However, there is also a growing number of lightweight, cross-platform, web-based design applications showing potential in urban design and architectural form design problems (Zhang et al., 2022; Ortner et al., 2023; Xu et al., 2023). As an approach of visualization and interaction, web platforms serve as ideal tools for design promotion and collaborative communication. Through the separation of core computational modules and user interfaces, web platforms can effectively enhance the ease of use for practitioners.

Focusing on the above-mentioned issues, this paper aims to explore the potential for mutual feedback among forms, metrics, and visuals in the early-stage architectural design. The effort is made to integrate rule-based modelling, conceptual image generation, and web-based platforms, unifying "form-metrics-visualization" into an interactive application. To achieve this goal, "SIMForms" is introduced as a web-based conceptual design assistant application that integrates parametric modelling with AI-based conceptual image synthesis (Figure 1). Through this web application, designers and stakeholders can, during the conceptual design phase, obtain diverse architectural style models based on simplified control parameters. Furthermore, the application allows the synthesis of rendering images through AI models, enabling the examination of generated results and providing design references.

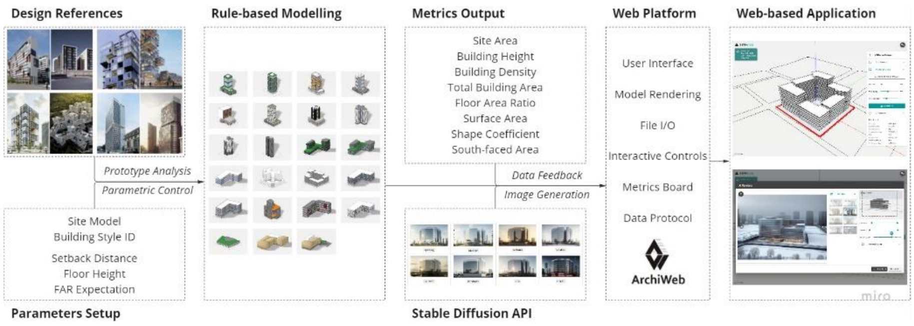

Figure 1. Workflow of SIMForms

2. Methods

2.1. PROTOTYPE ANALYSIS & PARAMETRIC MODELING

The parametric styles in SIMForms are derived from the analysis of real-world architectural design cases. The research team chose several examples of multi-story and high-rise public buildings from publicly available sources such as the internet and datasets, deconstructing the rules and geometric principles behind their forms. The current selection of cases aims to maximize diversity in form and revolves around different configurations of architectural elements. In terms of overall layouts, they include central enclosure, linear arrangement, and unit dispersion. In terms of operational techniques, they encompass strategies like volumetric displacement, chamfering, and stacking.

Inspired by prototype analysis, the basic generation rules for each architectural style were encoded through computer programming. All architectural styles treat storeys as basic volumetric units, considering them as stacked blocks regardless of their specific form. Facade or detailing rules are then refined based on the stacked blocks. Three fundamental parameters are employed in the generation rules to control the resulting forms while preserving their stylistic essence: storey height, setback distance, and FAR expectation.

- Storey height controls the height of each storey in the generated model.
- Setback distance simulates the architectural setback from the street and city boundaries. As the setback distance increases, the building footprint decreases, resulting in an increase in the total number of storeys, given the FAR expectation.
- FAR expectation is a parameter controlling the scale of the building. Using this value and the site area, the total building area can be calculated, and, based on the form rules of each building, a rough estimate of the total number of storeys can be deduced.

The selection of these three fundamental parameters reflects the objective of enabling designers to obtain different architectural models by adjusting values in a simple and intuitive manner. Behind these parameters, adaptive modelling rules have been defined for each style's generation process, including:

- In some styles, hidden parameters with random values are introduced, enabling control over aspects such as random wall insertions or random openings in facade grids. This feature results in variations in each generation under the same set of parameters.
- In certain high-rise building styles, the tower's bounding box is derived from the maximum inscribed rectangle of the site outline, utilizing optimization algorithms for iterative searches. This ensures the generation of effective and rational tower forms in various site shapes.

In conclusion, the goal from analysing design prototypes to parametric modelling is to incorporate the generation rules of different architectural styles into a straightforward control parameter framework. This ensures the preservation of style characteristics, diversity, and adaptability. The same architectural style can guide adaptive generation results under different parameters and site shapes (Figure 2).

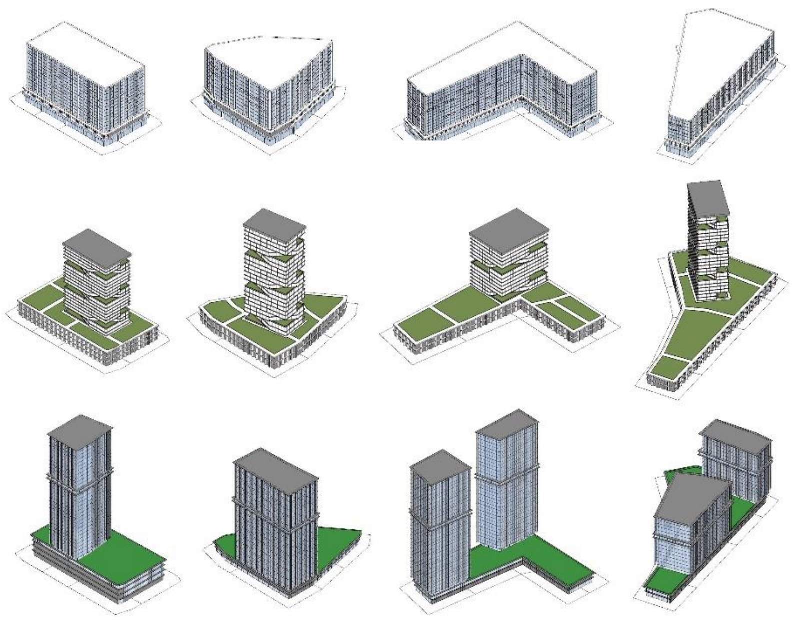

Figure 2. The results of the same style generated by different sites and parameters

2.2. METRICS CALCULATION

During the early-stage design, a crucial step is the rapid verification of basic technical indicators. As the creation rules of 3D models are encoded through computer programming, fundamental metrics can be obtained through simple geometric operations. In the parametric modelling phase, all created 3D elements include "elementType" attribute, allowing for the straightforward differentiation of the element's type. This attribute serves to filter whether an element is marked as a volumetric block or as a non-spatial component, such as windows, floor slabs, facade grids, or decorative elements. Given that the logic of parametric modelling is based on storeys, the volumetric block encompasses both volume and floor area information. These elements marked as volumetric block are then extracted separately for metrics calculation, fulfilling the approximate control requirements during the early design phase (Figure 3). SIMForms currently employs a set of 8 metrics for calculation and display:

- Site Area: The area of the site, representing the polygonal area of the user-inputted site.
- Building Height: The total building height, calculated based on the expected storey count derived from the FAR expectation and the user-inputted standard storey height.
- Building Density: The union area of the base polygons of all volumetric blocks projected onto the plane.
- Total Floor Area: The cumulative area of the base of each volumetric block.
- FAR (Floor Area Ratio): The floor area ratio, calculated as the ratio of the total floor area to the site area. The FAR at this stage represents the computed result after model generation and may differ from the user's inputted expectation, although they are theoretically expected to be similar.
- Surface Area: The external surface area of the building. It is calculated by obtaining the union of all volumetric blocks, forming the volumetric primitive, and summing the areas of each surface on the primitive.
- Shape Coefficient: The shape coefficient, calculated as the ratio of the external surface area to the total volume. The total volume is obtained by multiplying the base area of each volumetric block by the inputted floor height.
- South-facing Area: The area of south-facing facades. In certain architectural functions and specific regional requirements, the number of rooms facing south is a crucial indicator. The south-facing area is determined by calculating the angle between the normal vectors of each surface of the primitive and the vector pointing in the true south direction (0, -1, 0). Angles in the range of $[-\pi/2, \pi/2]$ are marked as facing south.

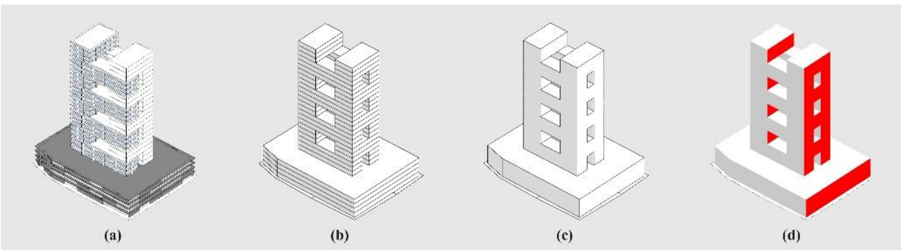

Figure 3. Taking the South-facing Area as an example, all volumetric blocks (b) can be extracted from the original generated model (a). The union of these blocks results in the total volumetric primitive (c). The specific faces can be identified and filtered from the primitive (d).

2.3. IMAGINARY SYNTHESIS

The AI Render backend employs diffusers to create a comprehensive pipeline. Operating on an NVIDIA RTX 2080Ti, it efficiently renders an image with a maximum edge of 1200 pixels in approximately 8 seconds before transmitting it back to the browser. Figure 4 depicts the complete workflow, showcasing how the browser captures preview frames from the canvas of the user-generated model. These frames are then relayed to a Python module in the backend where OpenCV's Canny algorithm retrieves their edges. These edge images function as control parameters, and together with user-defined generation parameters such as Render Style, Sampling Method, and Sampling Step, they integrate with the outputs generated by the pretrained Stable Diffusion model.

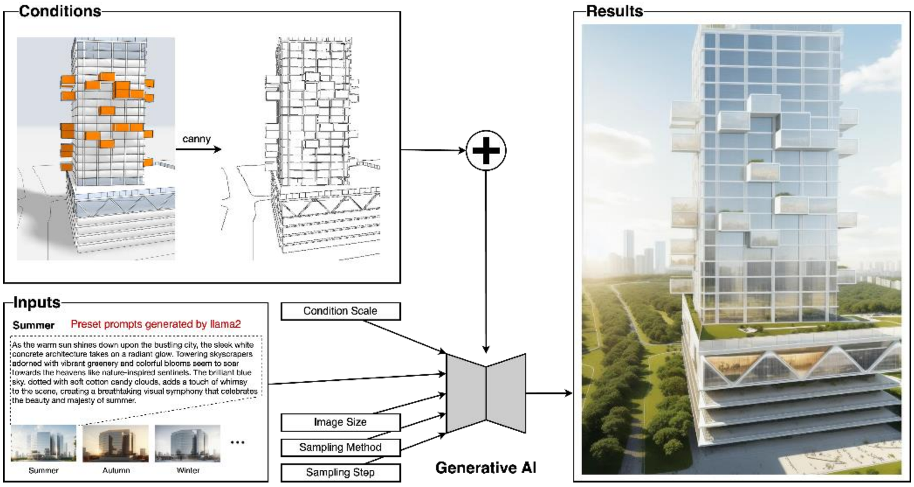

Figure 4. Backend workflow of imaginary synthesis with generative AI

The intervention of AI-generated images has accelerated the visual representation of parametric modelling, allowing users to evaluate and adjust the generated architectural forms based on conceptual images. It in itself represents a fascinating creative avenue for architecture.

3. SIMForms: An Integrated Web-based Application

SIMForms, as a web application, adopts the classical Browser-Server architecture, consisting of 1 browser module and 2 server modules: a web page based on the Vue framework, a modelling and metric calculation module compiled by the Java environment, and an image generation module deployed through Python. To facilitate data interconnection between modules and interactive control on the web page, the team developed the ArchiWeb platform, first released in 2021 (Mo, 2021). The SIMForms application has been deployed on a cloud server (Figure 5): https://web.archialgo.com/simforms/. The application comprises three operational modules: Site Configuration, Model Generator, and AI Renderer (Figure 6).

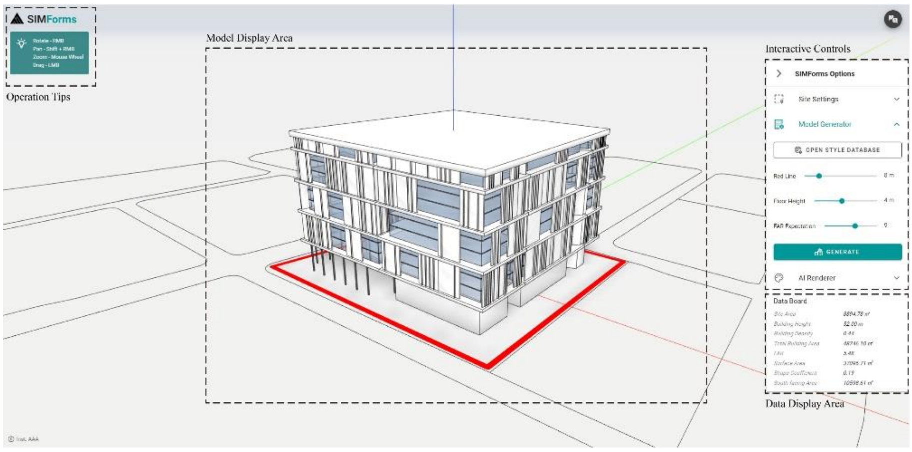

Figure 5. Main interface of SIMForms

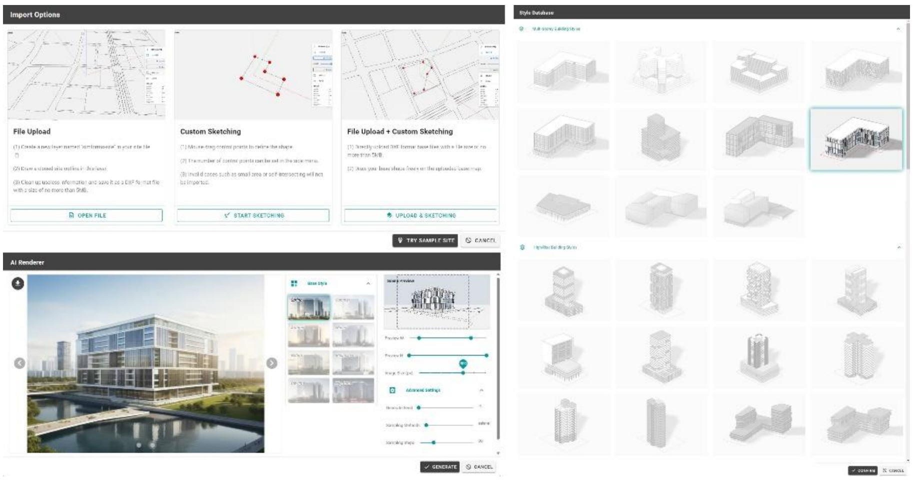

Figure 6. Interfaces of 3 Modules: Site Configuration (left-top), Style Database (right), AI Renderer (left-bottom)

The Site Configuration module requires users to choose one mode for defining the design base. Mode 1 allows users to upload a DXF file (a common AutoCAD file format) of the design site, which should include a layer named "simforms-site" with a polyline placed on this layer, identifiable in the application as the site outline. Mode 2 involves manual drawing, providing 3-8 control points that users can drag to define the desired site shape. Mode 3 is a combination of mode 1 and mode 2, allowing users to use the uploaded file as a base map and draw the desired site on it. Additionally, the application provides test case for users to quickly experience.

The Model Generation module consists of 23 selectable styles and three basic control parameters. The 23 styles are categorized into two groups based on multi-storey and high-rise buildings. A style database panel is provided for selection. After selecting one style, users can adjust three parameters: storey height, setback distance, and FAR expectation, generating the corresponding model. Each time a model is generated or updated, eight metrics are simultaneously calculated and updated on the data panel area. During the model generation stage, aggressive site shapes or parameters may result in the inability to generate effective models or excessively long generation times. The application provides feedback to users and suggests reconfiguring the shape or parameters.

The AI Renderer module includes camera parameters, rendering area, and rendering style. The camera parameters inherit the native camera adjustment functions of ArchiWeb, providing three functions: pre-set camera angle, isometric view, and camera FOV. After determining the related camera parameters, SIMForms uses the current scene as the original layout, allowing users to further select the rendering frame and image size. The application sends the rendering range, set by the user, to the AI Renderer backend. Current render parameters include eight base styles for convenient use: spring, summer, autumn, winter, nature, minimalism, daytime, and nighttime. Four advanced parameters are also introduced for fine-tuning the image generation effects: random seed, sampling method, samp ling step, and ControlNet conditioning scale. The generated images will be displayed in the preview box, supporting a maximum of the latest five concept images for comparison and download.

Figure 7 displays some of the building models and corresponding conceptual images generated through SIMForms. These examples are extracted from three semi-public tests conducted since SIMForms went online. Participants in the testing phase included students and professional architects, with a total of approximately 500 individuals. From October 17, 2023, to December 19, 2023, the server backend has recorded over 1700 sessions and 4100 operations, including model generation and image rendering actions. The purpose of the tests was to assess the server's stability, generation speed, and bug identification. The showcased results demonstrate the application's adaptability under diverse user input conditions, providing users with flexible creative inspiration.

Figure 7. Website usage data and results of various building models with corresponding images

4. Conclusion

This study introduces a comprehensive application for early-stage architectural design, named SIMForms, which combines rule-based parametric modelling, AI image generation, and the web framework based on ArchiWeb. In this application, users can interactively define design sites through a lightweight web interface, choose architectural styles, control 3D model generation parameters, and quickly obtain visual representations of architectural concepts along with metrics feedback. The main contributions of this research include:

- Bridging the gap between architectural form, quantitative metrics, and visualization. In the conceptual design phase, this application aids architects in evaluating various architectural forms under specified metrics (volume combinations, height variations, storey count controls, etc.), providing rapid feedback on corresponding effects, and serving as decision support for subsequent design stages.
- Integrating rule-based generative algorithms with the Artificial Intelligence Generated Content (AIGC), enhancing the visual presentation effects of generative design and parametric modelling. This introduces a new approach, connecting algorithmically driven computational design results rather than static 3D models or hand-drawn sketches with image generation engines.
- The application on a web platform not only facilitates the promotion, dissemination, and popularization of different architectural styles but also supports architects in sharing and communicating with clients and the public.

Planned future work includes expanding and categorizing the building style database, automatic matching of concept images with building styles, and expanding performance-related measurements for more design scenarios. Advances in computational hardware, software, and AI models will further reduce the complexity and barriers to entry for computational design applications, making it possible to apply digital technologies to comprehensive and diverse projects.

Acknowledgements

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