Impact of Design Sequence on Building Design with Generative Methods

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Abstract. This paper investigates the impact of design sequence on building design using generative methods. Through a case study exploring design sequences, the paper proposes a framework for enhancing explainability in building design processes. The sequence of design constraints, space approximation, candidate selection, and evaluation, helps provide comprehensive explanations for design choices. The study reveals correlations between design sequence and solution outcomes, emphasising the importance of support for sequence of architectural decision-making. Through integrating documentation and representation of sequences, the framework facilitates effective communication and collaboration among stakeholders. Future research will further explore diverse building types and design aspects to enhance the framework's scalability and applicability. Overall, the study contributes to advancing understanding and practice in architectural design, promoting dynamic and responsive approaches to complex design challenges.

1. Introduction

Building design is a complex process that involves multiple disciplines, including architecture, engineering, and construction. The success of any building project depends on effective communication and collaboration between these disciplines. However, building-design processes have become more complicated due to the involvement of increasing numbers of disciplines and the amount of design criteria (Gray and Hughes, 2001).

The complexity of design problems and their decision-making processes has been continuously explored over many decades. Jones (1966) proposed systematic design methods that enable a more public design process, allowing effective collaboration among individuals with varying levels of experience. Gero (1990) introduced the design ontology Function-Behaviour-Structure (FBS). However, a comprehensive framework to formalise design processes remain a challenge. Dubberly (2004) collected and presented more than 100 design theories, illustrating their complexity and the difficulty of summarising them into a general schema.

Furthermore, contemporary approaches using generative and AI-assisted methods draw upon other processes. Designers can now be presented with possible solutions before making a decision, as seen in examples such as the generation of architectural floor plans (Huang and Zheng, 2018) and options for building mass in terms of their energy performance at an early design stage (Singh et al., 2020). Advances in computing have increased the opportunities for reasoning with populations of solutions.

In the architecture field, representation of a design process includes an outline of the general stages and activities undertaken from the initial conceptualisation of a project to its finalisation. It typically involves stages, such as research, analysis, conceptualisation, development, refinement and documentation. For the purposes of this research, the design sequence refers to the specific order or sequence of stages followed within the design process. It denotes the sequential progression of design activities, indicating the logical flow of work from one stage to another. However, often only parts of the building design can be logically sequenced. For example, the sizing of the HVAC system can be sequenced in a "swimming lane" approach (de Wilde, 2018). However, this sequencing may occur before or after other design activities.

Pierre Nativelle (1729) provided guidance on architectural design during the 18th century. Jacoby and Neumeyer (2013) interpreted his approach as a top-down sequence to design, where the determination of a building's general scale precedes the selection of order and ornamentation. This contrasted with the classical bottom-up sequence, which started with choosing a pre-selected order and character. A correlation between a design sequence and its solution has long been observed. There is much potential of using design sequence to enhance explainability and thus improve design support.

Tschetwertak et al. (2017) displayed the influence of design sequence, by breaking a design problem down into stages of optimisation due to the high number of parameters. The result showed significant differences in Life Cycle Assessment (LCA) performance and the dependency of the appropriate sequence on individual design problems. The design problem becomes more complex when the design cannot be optimised due to the number of non-quantifiable parameters, such as aesthetics. Furthermore, there is an asymmetry between knowledge between stakeholders and designers (Augenbroe, 2019). This creates a need for improved building-design support that can effectively manage aspects such as design iterations.

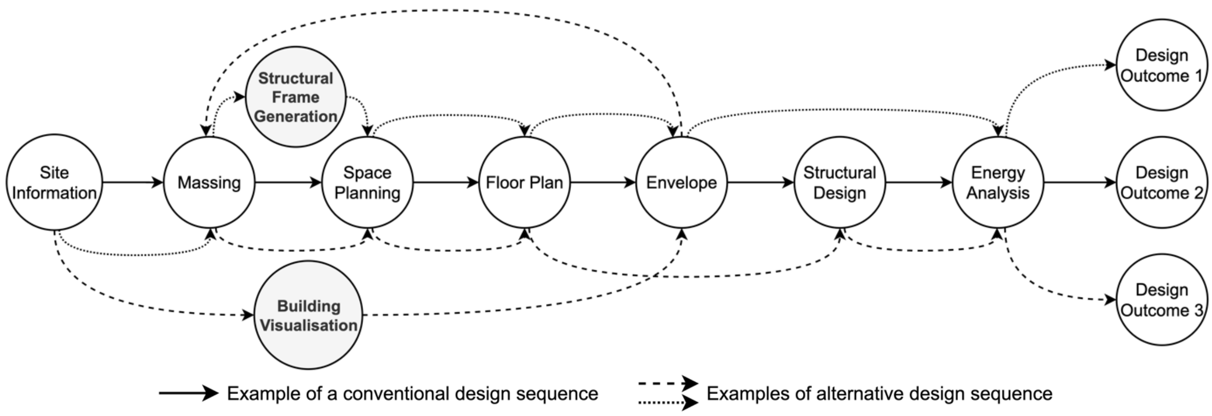

Figure 1: Possible changes in design sequence due to alternative design methods, shown in dashed and dotted lines

Figure 1 displays the change in design sequence with the presence of emerging design methods. It presents an example of typical design sequences, leading to a design outcome. The use of methods such as support for early decisions related to structural frame generation and building visualisation (shown in grey in Figure 1) often lead to deviations from conventional design sequences, resulting in other design outcomes. The knowledge and documentation of the sequence thus become more important when explaining design decisions.

This paper is an extension to previous work that explored the explainability and impact of design sequences using manual design methods (Li and Smith, 2023).

This paper describes an investigation into design sequence, through understanding and quantifying its impact on outcomes in the context of generative design in building projects. An examination of the design decisions at various stages in a sequence is included. Also, a framework that improves the explainability of design decisions is evaluated.

2. Methodology

Conventional design sequences vary according to alternative and emerging design methods. A theoretical framework (Figure 2) is proposed to explore methods for enhancing the explainability of building design processes. Once mandatory constraints are applied to generate a design space, the designer proceeds to establish and define a sequence of criteria to further refine the solution space. The sequence of criteria and solutions are documented, evaluated and represented to provide a more comprehensive understanding of the design solutions. In the event of a design amendment, the designer is able to effectively trace back to specific stages, minimising time and costs while preserving the integrity of the design.

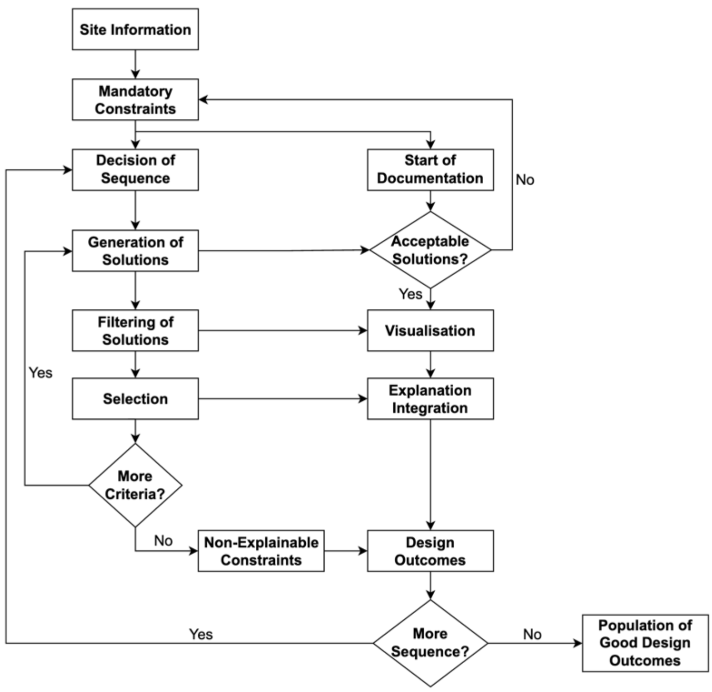

Figure 2: A proposed framework to support design explainability by documenting, evaluating and visualising generated solutions

A case study is conducted to explore the framework being applied to a building project. The selected site has an area of 2000m^2, drawing inspiration from an apartment project in Newcastle, Australia. The site is characterised by its elongated and narrow shape, with close proximity to neighbouring buildings. Additionally, it is situated within 250m of a water body, making its view a primary design consideration alongside factors such as privacy, unit mix, aesthetics, and the constraints posed by its narrow dimensions.

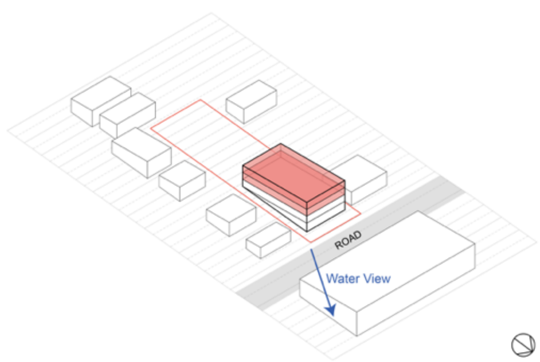

Figure 3: Building site and context

Software programs with generative solutions are implemented to generate solutions. Archistar (Archistar, n.d.) is used for massing. Parameters such as site boundaries, required floor space ratio, maximum building height, maximum site coverage, unit mix and site setbacks are used as inputs. The result displays massing configurations that fit these requirements. The resulting configurations also provide guidance on natural ventilation, counting the number of units with two or more orientations, being able to have cross ventilation.

PlanFinder (PlanFinder, n.d.) is used for floor plan layouts. As parameters such as the unit outline, entrance location and number of bedrooms are defined, solutions for floor plan configurations are generated. Efficiency is provided as a measure of space not used for circulation.

Veras (EvolveLAB, n.d.) is used for building visualisation. A base image and a text prompt are used to produce a visualisation of the intended outlook of the building.

Two design sequences are evaluated for this study:

A. Massing – Floor Plan Layout – Building Facade
B. Building Facade - Floor plan layout - Massing

3. Results and Analysis

3.1 Sequence A (Massing – Floor Plan Layout – Building Facade)

Sequence A follows a conventional design sequence, addressing building aspects in a converging order from general to detailed. Inputs such as the site, floor space ratio, maximum building height, unit type mix, and setbacks are considered, and design options are generated in the massing stage using the online platform Archistar.

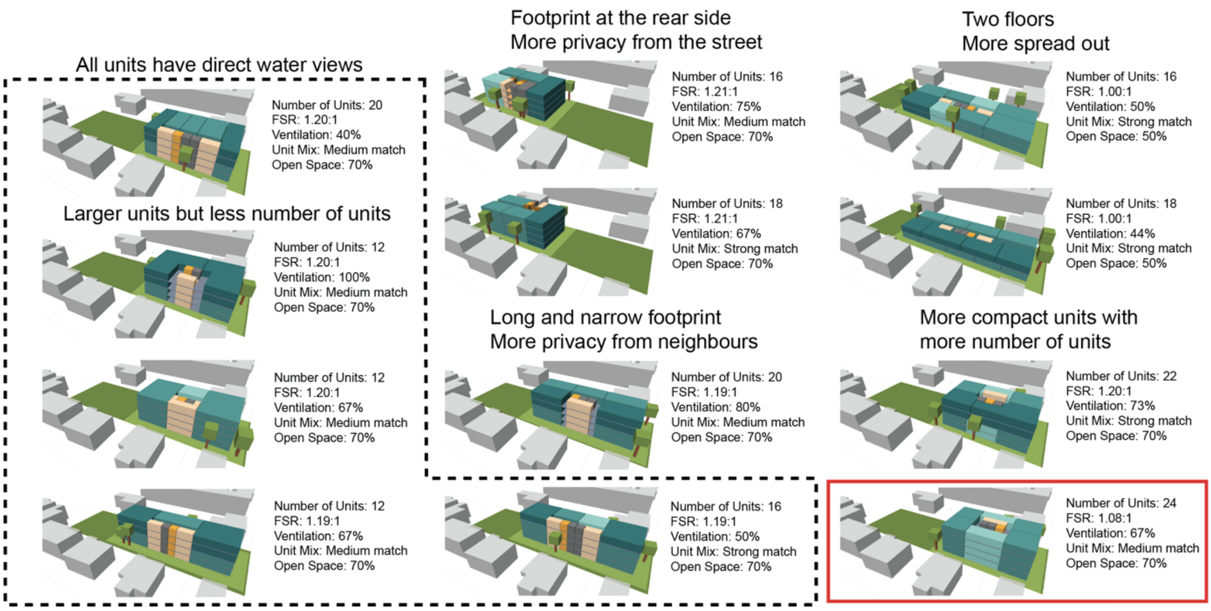

Figure 4: Clustering of massing options showing the range of possible solutions

Numerous solutions are generated, which designers can interpret to provide explanations. For example, a long and narrow building footprint could offer increased privacy from adjacent properties. These explanations can be organised into groups (Figure 4). For water views, the mirrored configurations of the solutions are also considered during the grouping. To achieve an appropriate number of units, including those with direct water views, one of the options from the “more compact units with a higher number of units” cluster group (highlighted in the red box in Figure 4) is selected to advance the design.

As the preliminary unit division are determined from the massing option, it is adapted manually to accommodate for the design needs (shown in Figure 5), for example, some balconies are created to face the water body. The core area is also reduced to increase its efficiency.

Figure 5: Unit division following the selection of a solution in Figure 4

After determining the unit division, internal floor plans are generated using the PlanFinder software. An example is provided for one of the units at the front (highlighted in the red box in Figure 5).

Figure 6: Display of design options for a unit highlighted in Figure 5

The design options are generated and grouped to provide a better overview of the available outcomes (as shown in Figure 6). To prioritise the views and room sizes, the option marked in red in Figure 6 is selected to proceed with the process.

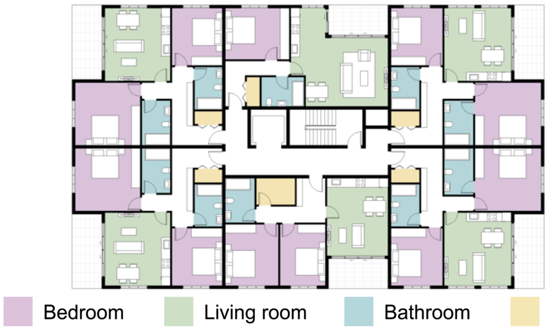

Figure 7: Typical floor plan formed with the plan selected in Figure 6 (left)
Figure 8: A basic form of the entire building formed from the typical floor plan (right)

Utilising the same methods for all the units a typical floor plan (Figure 7) is created and replicated for other floors to establish a basic form of the apartment building (Figure 8). It is assumed initially that floor-plan decisions are independent of the choice of material. With the input of the provided geometry and a text prompt describing the desired outcome, a rendered image is generated using the software Veras, see Figure 9.

Figure 9: Design options for building facades

Images are generated for each text prompt. Each option provides an indication of how the building can be articulated to reach the final outcome. It is observed that the degree of change in the building form is limited, primarily focusing on materials. The solutions can be grouped according to the text prompts that were entered. These design options serve as a guide or source of inspiration for designers to adapt the choices to their designs, drawing upon their experience and knowledge.

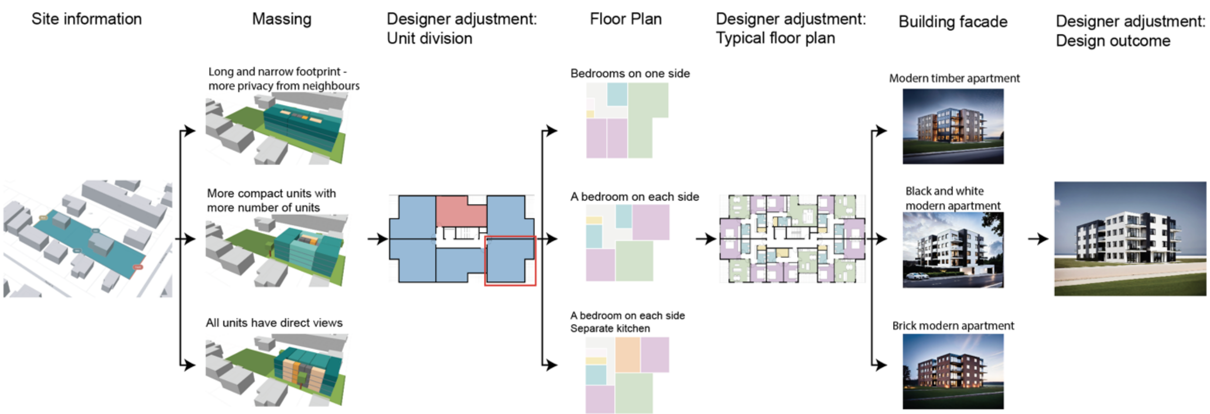

Figure 10: Decision tree of the design sequence

A decision tree is created to document and represent the process (Figure 10). It provides improved transparency for understanding the clusters from which decisions are made. As changes are requested (or required), the corresponding elements can be traced back and adjusted efficiently.

Table 1: Examples of requested changes and how they are traced back for resolution in the sequence

Requested change	Stage to be traced back to	Group for resolution
Use timber cladding	Building facade	Modern timber apartment
A building with curved elements	Building facade	Modern apartment with rounded balconies
Add a separate kitchen	Floor plan	A bedroom on each side | Separate kitchen
All units require a direct water view	Massing	All units have direct views
Similar units but combine two units	Massing	More compact units (same group)
A longer and narrower footprint is required for privacy	Massing	Long and narrow footprint
A building with curved elements and single balconies across the entire facade	Start another sequence	

Several scenarios illustrate how changes are addressed (refer to Table 1). For instance, a modification to the building facade requires tracing back one step to explore options for the facade. Depending on the nature of the change, alternative solutions are identified from the same or another group. However, a significant change necessitates branching into another sequence, such as requesting the incorporation of more prominent curved elements and reducing the number of units for the facade to maximise the property value of each unit.

3.2 Sequence B (Building facade - Floor plan layout - Massing)

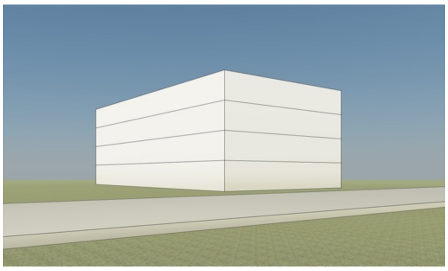

Figure 11: Basic outline of the building from mandatory constraints

As described at the end of Section 2, the second sequence involves building facade - floor plan layout - massing. A basic form (Figure 11) is outlined using the site information and dimensions to establish a general sense of the building's scale. The same method used for building facade in Sequence A is then applied to generate the renderings based on the form outline and text prompts (Figure 12).

Figure 12: Design options for building facades, using Sequence B

As opposed to Sequence A, Sequence B offers a significantly wider range of choices, enabling the creation of distinctive shapes for building elements. A decision (highlighted in the red box in Figure 12) is made to prioritise curved elements and incorporate single balconies across the entire facade. This selection necessitates having only one unit at the frontage. Similar methods to those used in Sequence A are employed for the remainder of the design.

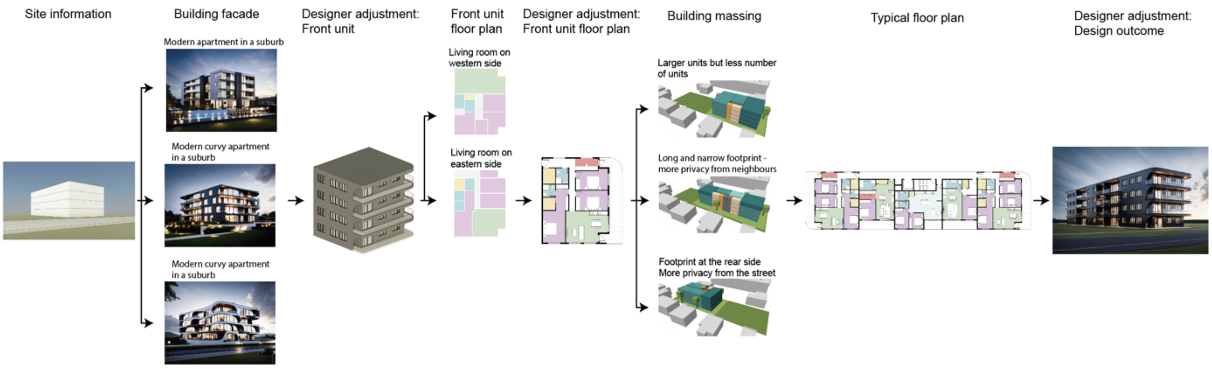

Figure 13: Design tree of Sequence B

A decision tree (Figure 13) is also made for Sequence B to summarise the process. Initially, a model of the front unit is created to replicate the selected style of the building facade. Some elements are determined including colour, facade, window sizes and front unit configuration. With the outline of the front unit determined, its floor plans are generated and one of the solutions is selected for having water views in the living room.

Once the floor plan and width are determined, there is little variation in the massing and the remaining units. At the stage of building massing, the options in Figure 4 are considered again. With one unit as the frontage, a longer and narrower building footprint is favoured to prevent the front unit from becoming excessively wide. As the unit division is determined from the massing, a typical floor plan and its final outcome is reached (Figure 13). It is observed that there is a greater degree of freedom for the building facade as it is considered earlier in the process. For example, changing some of the windows at the front unit may require tracing back to the first stage.

4. Discussion

The case study demonstrates the divergence in outcomes and progress resulting from varying design sequences, highlighting the potential usefulness of documenting and representing groups of design options identified by generative design methods. This presents an opportunity to offer detailed explanations for design outcomes and enhance traceability when changes occur.

The role of designers in the process remains crucial. Designers need to have an overview of the possible solutions in given conditions. Their domain knowledge and experience enable them to categorise and select solutions. For both sequences, designers' adjustments between each stage are important for guiding the sequence. Selected solutions are adjusted to further satisfy flexible constraints such as aesthetics and views.

Some changes in parameters are quantifiable. For instance, by measuring the window-to-wall ratios of the observable sides of the buildings, the solution at the conclusion of Sequence A (see Figure 10) shows a window-to-wall ratio of 35%, whereas the options presented in Sequence B (see Figure 12) range from 19% to 48%. Given the significance of the window-to-wall ratio in considerations such as energy consumption, the change in design sequence is demonstrated to have an impact on these parameters.

Furthermore, the study unveils the evolution of design parameters throughout a sequence. As Sequence A follows a more conventional approach, the design solutions converge from general to detailed. It is noted that some available options in later stages of Sequence B significantly diminish as numerous aspects of the buildings are determined earlier in the process. Sequence B includes an early-stage visualization of a completed building, which determines parameters such as window sizes, floor plan layout and massing. Consequently, in contrast to the massing options for Sequence A, Sequence B has a limited set of options by the time it reaches the massing stage.

5. Conclusions

The study reveals a shift in the role of designers as they encounter numerous options at each stage, unlike traditional iterative methods. Documenting and grouping solutions become crucial for explaining design decisions and ensuring traceability in case of changes. Furthermore, the evolution of constraints in generative design sequences displays the significance of their orders. A relationship is formed between design sequences and building elements. With the emergence of additional design constraints such as energy consumption (window-to-wall ratio) and user experience (views), their dependency on certain design aspects determines the order of a design sequence. The approach builds on the observation that designers adopt sequential approaches, thus addressing the limitations of conducting simultaneous multi-criteria evaluations for entire buildings.

Architects and designers are encouraged to use this approach to adapt to new generative design methods. For more complex design constraints, a new type of designer with knowledge in computational methods will be required to generate suitable populations of solutions. This approach also raises awareness of explanation in design education, as design students can now be presented with solutions without necessarily understanding them. This contrasts with the conventional process of reaching a solution only at the end. There is thus an increased need for students to interpret and understand the solutions they select for each generation.

It is expected the framework will foster effective communication and collaboration among multidisciplinary teams. This case study displays an example of residential design, which has relatively well-defined constraints and solutions. Other building types, such as public and sports buildings, are more complex and require clearer definition of constraints from designers and stakeholders. The concept of explanation becomes more important, as there might be more changes to constraints during design processes. Future work will expand applicability across diverse building types and incorporate additional design considerations.

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