Explainability for Support of Open-Sequence Building Design

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Abstract. The trend of increasing specialisation adds complexity to the building design process, as designs are now expected to meet a multitude of diverse requirements and needs. The reliance on experience and individual heuristics in completing designs has resulted in a lack of explainability, making designs vulnerable to integrity loss, especially when changes occur. A case study is conducted to explore the design workflow in a building design context, where design constraints and task sequences are open (unrestricted). Processes include data collection, constraint definition, design space approximation, candidate-design selection and evaluation. An understanding of the design-decision sequence forms part of the explanation for each candidate design. Documentation and representation of sequences are integrated for better explainability and communication. This study leads to a framework that enhances explainability in building designs where designers choose their task sequence. This framework is expected to facilitate effective communication between partners and optimally accommodate design changes.

1. Introduction

The process of building design has become increasingly complex due to the significant expansion of specialised knowledge and the involvement of various contributing organisations (Gray and Hughes 2001). Architects and designers are tasked with producing design concepts that satisfy their clients' needs and expectations while also meeting numerous requirements and regulations, including zoning laws, building codes, and safety regulations, among others. Additionally, there may be aesthetic considerations, such as the desired style or character of the building, as well as practical concerns such as the building's function, sustainability, location, and budget. Furthermore, building design processes predominantly rely on experience and individual heuristics.

Problems related to design have been described as “wicked” problems, involving an argumentative process where the solution emerges gradually among participants (Rittel and Webber 1973). Since a design solution is not solely determined by the logics of its problem, there is “no sequence of operations which will guarantee a result” (Lawson 2006, pp. 123-124). An open-sequence design process is applicable to building design.

General support is possible through an open-sequence process model where the designer and other domain experts are at the centre. The order in which designers consider requirements influences the final design. Boulanger and Smith (2001) noted the importance of design sequence in structural engineering, as it affects the efficiency and range of design solutions. Clarkson and Hamilton (2000) introduced the concept of “signposting” in aerospace design, to capture the design process and identify appropriate routes for engineers. However, building constraints defined by designers can encompass a complex and diverse set of requirements such as aesthetic outcomes, functional layouts and sustainable design considerations.

The reasoning behind each design decision as well as the order in which decisions are made are often adopted by designers intuitively. However, when completed designs are presented, they lack explainabilitiy which makes them vulnerable to loss of integrity in situations when changes occur.

Non-explained design decisions can have a range of negative consequences in the AEC industry. One of the most severe consequences is the potential for inadequate forensic information following building failures, which can result in significant harm to people and property. In the event of a building collapse, structural engineers may be called upon to explain their design decisions in court, which can have long-term legal and professional implications. For instance, the walkway collapse at Hyatt Regency Hotel in Kansas City, USA was traced back to a design change made to the walkway's steel hanger rods (Baura 2006). Lack of explainability in design decisions for architects can cause project delays, safety issues and non-compliance challenges. Furthermore, it becomes difficult to identify opportunities to optimise building performance and reduce energy consumption, resulting in less efficient solutions.

In building design, various methods have been implemented to improve the communication among parties. For example, design decisions were documented with explanation tags and pieces of design were stored as design episodes (Zahedi et al. 2022). Explainability has been implemented in an intelligent design assistant to support architects' design decisions with confidence, by supplying similar cases and explanation along the design process (Bielski et al. 2022). The exploration of design spaces using variational autoencoders for bridges has enhanced explainability by informing designers about the relationship between model features and performance (Balmer et al. 2022). While design decisions have been documented and performance metrics have been evaluated, the support for open decision-making sequences in building design has been limited.

In a conventional building design process, a designer makes a series of decisions using information such as context, specification and domain knowledge until a solution is reached. The emergence of novel analytical techniques for buildings has created the opportunities for designers to incorporate various analyses early in the process. For example, Singh et al. (2020) proposed a method to compare multiple design options in terms of their energy performance at the early design stage. In the context of generative design, a solution space is first defined by the product definition, design variables and constraints to generate a solution set before evaluation, filtering and selection of a solution (Mukkavaara and Sandberg 2020). These processes offer increased efficiency and the ability to explore a wider range of design options. However, it also presents new challenges in terms of explainability. When and what decisions are made throughout the design process becomes critical.

This paper contains an investigation into the concept of explainability in building design processes. It examines design decisions in various sequences formed by designer-defined constraints. This study aims to propose a framework that incorporates explainability to improve communication and design decisions for unrestricted (open) decision sequences. The framework is evaluated through a case study.

2. Methodology

As a designer defines a specific design sequence, the design constraints would form a hierarchical relationship, even when they are independent from each other. Understanding the sequence of when the constraints are applied informs about the reasoning behind the design decisions, especially for conflicting constraints. It displays the designer's preference for the placement of each constraint in the sequence, as a design constraint would be more preferred if it is placed earlier in the process.

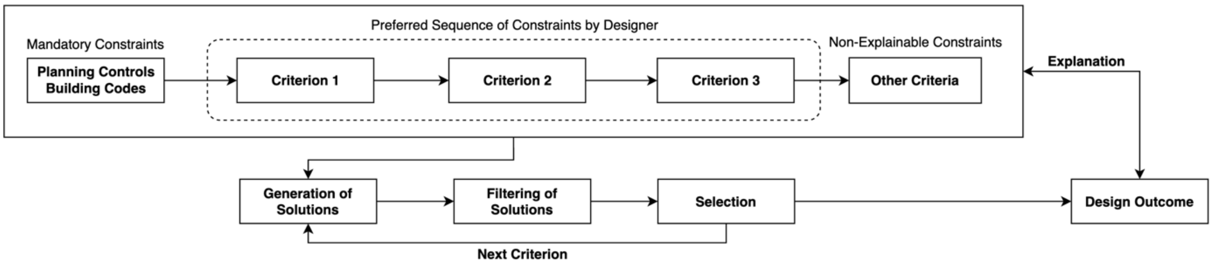

Figure 1: A design workflow to support design explainability

A theoretical framework (Figure 1) is proposed to enhance the explainability of a building design process. After obtaining the design space from mandatory constraints, the sequence of criteria is defined and set by the designer to narrow down the solution space. Other non-explainable constraints are design considerations that are too complex or non-quantifiable, such as aesthetics and context. In the case of a design change, the designer, with a clear picture of the steps in the design process, traces back to a particular step in the process, minimising the cost and time of design changes.

A case study is conducted to investigate the decision-making process involved in a building project. The selected site for the study draws inspiration from a design project situated in Newcastle, Australia. The site covers an area of $2000m^2$ and is located in a mixed-use zone, where the proposed building consists of four storeys with a commercial shopfront on the ground floor and residential use for the rest of the building. The proximity to the surrounding water body, which is within 250 m, has a significant influence on the design (as shown in Figure 2). The design of a typical building floor plan is examined for this case study.

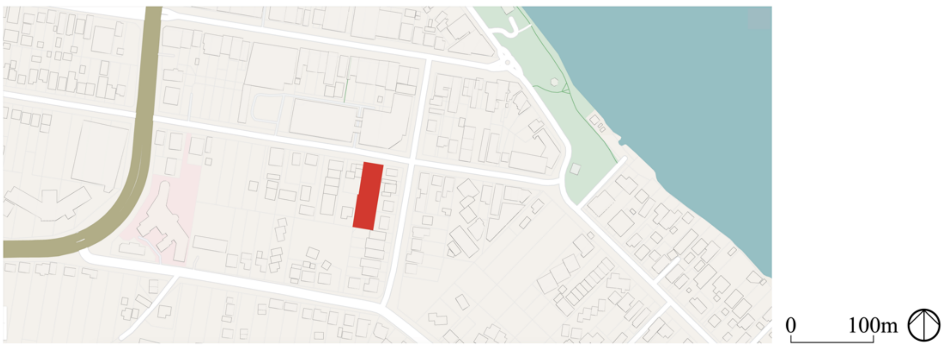

Figure 2: Site Location and Context

The design space is initially formed from the allowable setbacks to comply with the local planning controls (as shown in Figure 3). Visual privacy is a major consideration due to the long and narrow shape of the site, as it is situated close to its adjacent properties. The orientation and position of openings becomes critical, to minimise overlooking the neighbouring windows and private open spaces. According to the state Apartment Design Guide (NSW Department of Planning and Environment 2015), buildings up to 4 storeys are to have habitable rooms and balconies 6m to the side boundaries. Additionally, preferred constraints have been set, including that it must be a single building and have a 5m front setback to maintain the streetscape frontage.

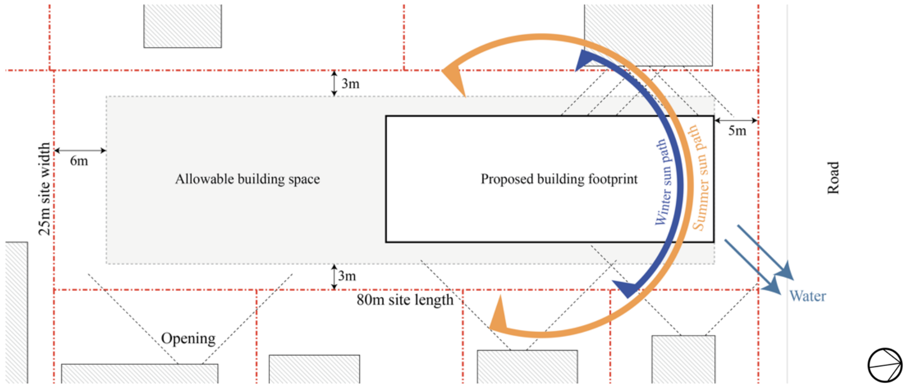

Figure 3: Diagram of the site considerations and constraints. In the Southern Hemisphere, north exposures have the most sun exposures

The immediate site conditions are also depicted in Figure 3, highlighting the site's relationship with sunlight, visual privacy, and views. These factors are the main considerations for the building's design. The study involves forming and testing various design sequences based on the preferred design considerations.

Three design aspects, namely views, thermal comfort, and flexibility, are determined to be critical in this study. One of the primary considerations is maintaining visual privacy while offering a clear view of the surrounding water body. As the building is situated in a warm temperate climate zone (Reardon 2013), passive design principles are implemented to ensure maximum passive cooling and heating for thermal comfort. Flexibility is also a crucial factor in apartment design to accommodate future changes in household structures.

Although the three design aspects are independent, the design spaces from each aspect may overlap or conflict with one another. For example, room orientation towards sunlight and views might not align. Similarly, the building's geometry necessary for flexibility may differ from that required for thermal comfort. These aspects are analysed during the floor-plan design stage, where the unit layouts, room designs, and openings are determined. To ensure a fair comparison between the design sequences, the floor space ratio to the site area is kept consistent at 1:1 for each sequence.

Two design sequences are evaluated for this study:

A. Views - Thermal comfort – Flexibility

B. Flexibility - Views - Thermal comfort

3. Result and Analysis

3.1 Sequence A (Views – Thermal comfort – Flexibility)

To begin the design process, the building footprint is determined based on the available view from each unit. The division of the units and the location of the corridor, lift shaft, staircase, and service area are estimated at this stage.

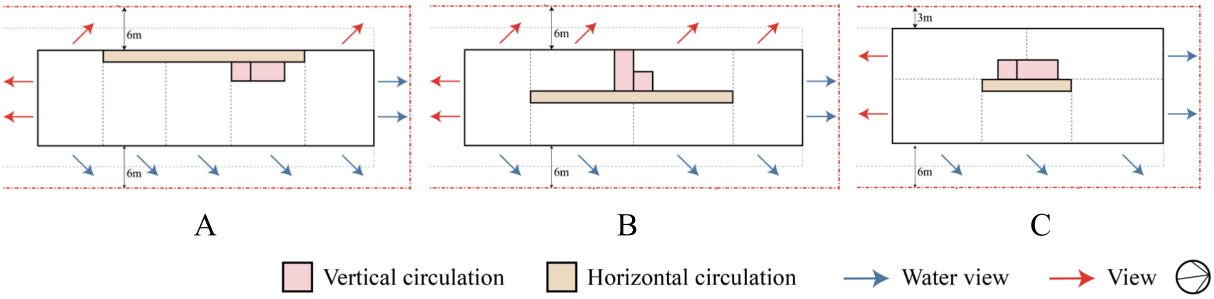

Figure 4: Design options for views

As shown in Figure 4, three design options are generated by prioritising available views from each unit. In order to have open views on all sides, Option A has the setback of 6m on both sides. To prioritise the water view for every unit, Option B has the circulation spaces on the western side. Option C has the western side setback of 3m, to increase the width of the building while maintaining the open water view on the eastern side.

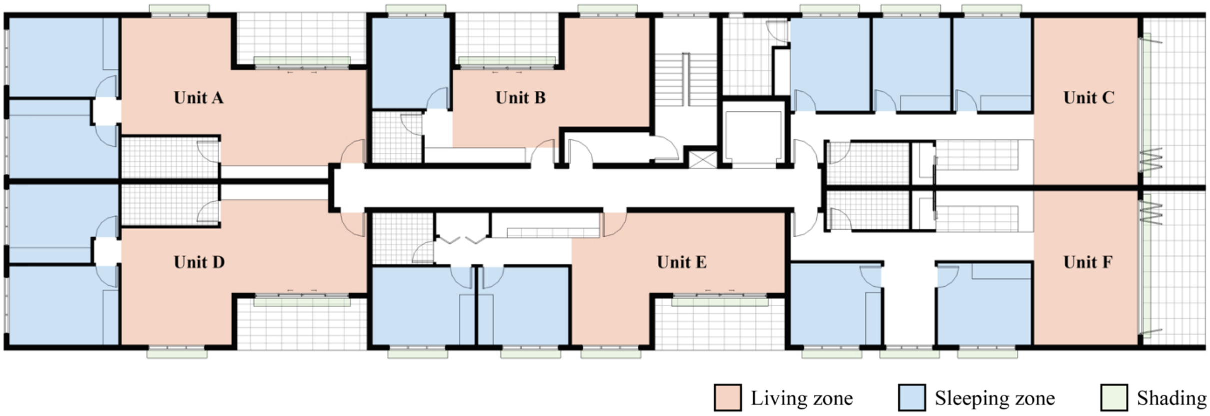

Figure 5: Design option for thermal comfort

Option B is further developed in consideration of thermal comfort, using passive design principles. As shown in Figure 5, main spaces and openings are identified. Living zones are placed towards the north and sleeping zones are placed towards the south. Therefore the units in the south contain bedrooms instead of having balconies facing the back of the site. Units with two-sided orientation allow for natural cross ventilation. External shadings are proposed to prevent excessive direct sunlight in summer.

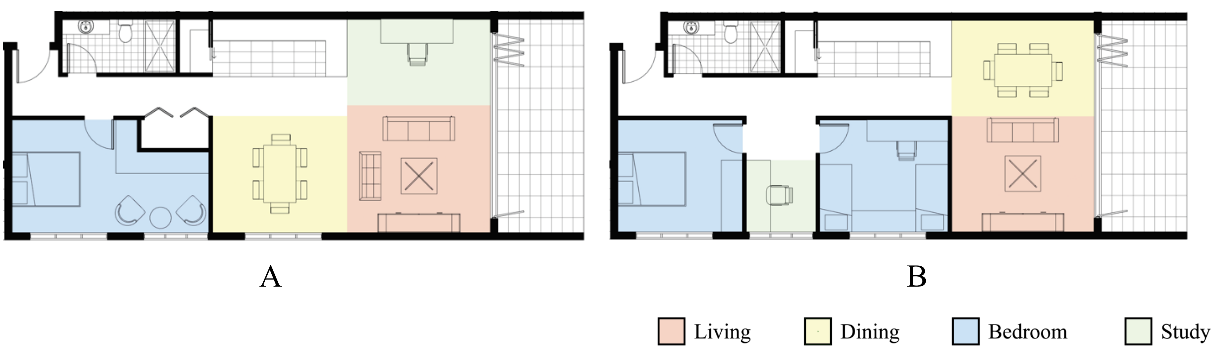

Figure 6: Alternative floor plans

Flexibility is the final constraint to be considered. Alternative floor plans (Figure 6) for the north-eastern unit (Unit F in Figure 5) are created to explore its flexibility. As the unit has two sides of orientation, a sufficient degree of flexibility can be achieved by opening up one of the bedrooms. Various arrangements can accommodate changing household structures such as a single person, a couple and a family with children. As the unit is long and narrow, the location of the bedroom has to remain at the eastern side.

3.2 Sequence B (Flexibility – Views – Thermal comfort)

By prioritising the flexibility of the units, the design sequence aims to create a floor plan that can accommodate changing household structures and lifestyles. According to Živković and Jovanovic (2012), the geometry and orientation of a building play a crucial role in increasing the flexibility of an apartment floor plan. A more compact form and multiple sides of orientation can allow for various room arrangements and uses. This, in turn, increases the adaptability of the space to the changing needs of the residents. Therefore, the compactness and multi-sided orientation of the units are prioritised to enhance their flexibility.

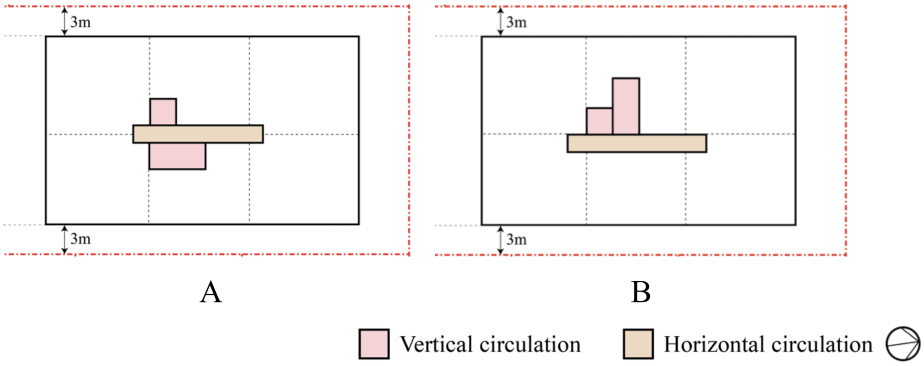

Figure 7: Design options for flexibility

Two design options are created to increase the flexibility of the apartment floor plan. As depicted in Figure 7, the options have the minimum side setbacks to have a more compact building footprint, which results in four units with two-sided orientation and two units with one-sided orientation for each option. To keep the geometry of the units compact, only the location of the circulation spaces are varied. Option B is further developed to include consideration of the water view and the views around the site.

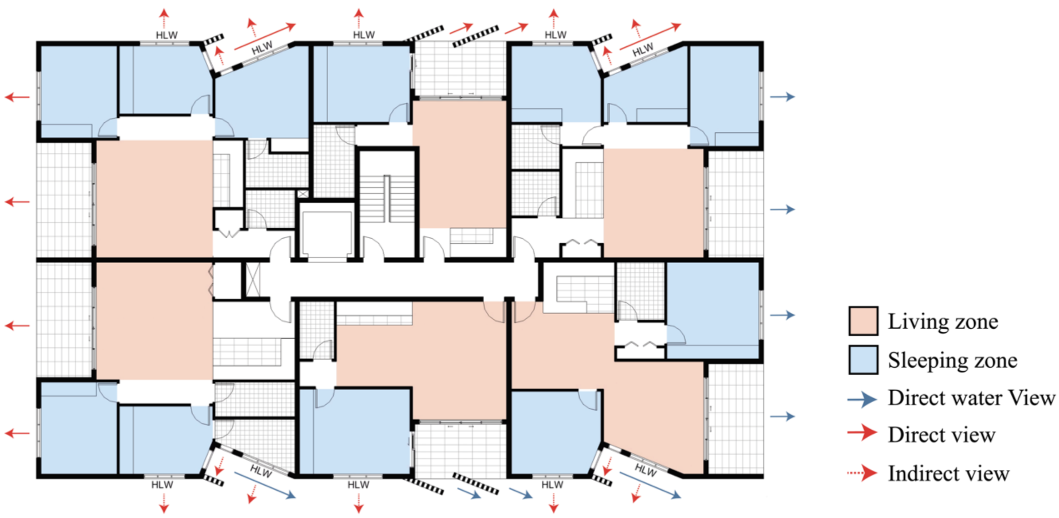

Figure 8: Design development for views

As shown in Figure 8, the main zones are oriented and arranged to prioritise the views from each unit. For the two sides which should minimise direct overlooking of rooms and private open spaces adjacent to the apartment due to their setbacks, openings are proposed to be either high windows or reoriented with privacy screens, to maximise views while maintaining visual privacy with the adjoining properties.

Figure 9: Design development for thermal comfort

The zoning of the units for thermal comfort is examined, given that the living and sleeping zones have been previously determined by the views. The design is developed in consideration of thermal comfort (Figure 9). As the main viewpoints are oriented towards the north direction, most of the zones coincide with the passive design principles that advocate for living zones to be oriented towards the north and sleeping zones towards the south. Additionally, the highlights and reoriented windows act naturally as louvres to block excessive eastern and western sunlight. There is a significant overlap of design spaces between thermal comfort and views. The exceptions are the two bedrooms facing north and the two living spaces facing south. To enhance thermal comfort, the northern openings are shaded to prevent overheating, and the southern openings are enlarged to maximise natural skylight.

Figure 10: Alternative floor plans

The aspect of flexibility is revisited to be compared with the outcome of Sequence A. Like for Sequence A, the north-eastern unit is further examined (Unit F in Figure 9). Similarly, the unit as an outcome of Sequence B allows for different space arrangements to accommodate a changing household structure (as shown in Figure 10). Due to the more compact geometry of the layout, the two sides of the unit allow enough width to accommodate a bedroom on either side, thus making more variety of arrangements possible.

4. Discussion

In this case study, two design sequences result in design outcomes with contrasting characteristics. Sequence A results in a design which is longer and narrower, allowing more views and direct sunlight into the units. The design from Sequence B is more compact, allowing for more flexible arrangements in the units. Apart from the conflict between views and flexibility, there are also cases when design solution spaces coincide. For example, when views and sun direction are both towards the north, their solutions for steps such as unit orientation are similar.

A hierarchy of design preferences is displayed through each sequence. A design aspect holds more weight if it is considered earlier in the process. In this case, views are the most important in Sequence A and flexibility is the most important in Sequence B. Various strategies are implemented for a design aspect depending on its place in the sequence to achieve the desired outcomes. The factors affecting the design outcome for each design aspect are summarised in Table 1. For example, considering views early in the sequence would affect the entire building geometry, while considering thermal comfort later in the sequence affects smaller elements such as the shading device.

Table 1: Factors affecting each step for a building layout design

Design Aspects	Building Envelope	Space Planning	Floor Plan	Openings
Views	Building geometry	Unit orientation	Room orientation	Opening direction
Thermal comfort	Building geometry	Unit geometry and orientation	Room zoning and orientation	Shading device and opening size
Flexibility	Building geometry	Unit geometry and number of sides	Room arrangement	Opening location

5. Conclusion

This paper introduces a framework that enhances explainability in building designs where designers choose their task sequences.

The work described in this paper leads to the following conclusions:

- This framework encourages a more transparent design process, where stakeholders and designers have greater visibility into the decisions made in a design.
- In an open design sequence, designers are encouraged to be aware of their sequence of decisions.
- By breaking down the design sequence, the framework is expected to also enhance flexibility, enabling designers to adapt more reliably to changing design requirements and constraints, such as evolving user needs or site conditions. If a constraint changes, designers have a clearer awareness of the elements that are affected by it.

- The case study demonstrates how design constraints and the order in which they are considered is related to the final outcome, and illustrates the hierarchical relationship between these factors in a design sequence.

This framework is particularly relevant in the context of emerging design methods that rely on generative design and artificial intelligence. As these methods shift the role of designer towards defining and inputting constraints and away from layout generation, explainability becomes more critical. The effectiveness of the proposed framework will be tested and integrated into emerging design methods to ensure its applicability and scalability. Furthermore, the suitability and scalability of the framework will be tested by applying it to various building types and considering other design considerations beyond the ones presented in this case study. Future work will also involve the study of explainability in the context of interdisciplinary collaboration.

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