THE POLYMORPHIC DIAGRAM

On mediating spatial thinking in architecture design

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Abstract. This paper describes the polymorphic diagram, a conceptual building information modeling environment conceived to mediate spatial thinking during the conceptual design phase. In particular, the discussion is focused on how enabling multiple forms of representations can possibly support and improve architects’ cognitive capacity to reason about space configuration.

Keywords. Space configuration; conceptual design; diagrams.

1. Introduction

The conceptual design workflow has been described as the most cognitively intensive phase of the whole design process (Kim et al 2008). Architects mediate the complexity of the conceptual design phase through iteratively modeling the design situation, structuring the relationships between the various entities of the design situation (Cross 2007). Drawing on literature concerning design studies and cognition, the traditional diagram has been the most dominant means of modeling or “structuring” the design situation. Diagrams have been recognized as the architect’s dominant medium of thought and knowledge creation (Herbert 1993). Thinking with diagrams enhances the architect’s mental ability to manipulate design knowledge and information (Do and Gross 2001), enabling the architect to bridge the gap between the design problem and the conception of a fitting and responsive solution (Alexander 1964).

Nevertheless, it may be observed that, despite of diagrams’ invaluable role in thinking during the conceptual design phase, emerging shifts in contemporary design production are imposing significant limitations on the cognitive
and developmental traits of the traditional conceptual diagram. In contemporary design workflows, a holistic examination of knowledge and information is rapidly becoming a critical criterion for effective architectural production. That is to say, designers require a conceptual design medium that enables them to seamlessly interact with larger sets of information that can be reliably and readily integrated, transformed, repurposed, and communicated. Diagrams are becoming increasingly limited in these regards.

These limitations in representing and manipulating the complex matrix of design knowledge and information have prompted urgent demands to investigate new design mediums to support architects during the conceptual design phase. A prominent approach has focuses on developing design systems that augment the cognitive traits of diagrams with layers of computation and information technology.

In its contribution to this space of research and development, this paper describes the polymorphic diagram, developed and conceived to support an important cognitive capacity for conceptual design thinking: spatial reasoning through multiple representations of design knowledge and information (Lawson 1997; Akin 1998). In essence, the polymorphic diagram is a conceptual building information model that supports structuring the design situation by allowing design information to be represented and repurposed in various forms of abstractions and different levels of complexity.

2. The polymorphic diagram

Following the same fundamental principle as BIM technology, the polymorphic diagram enables the structuring of design knowledge in a central and integral repository. Then it allows the designer to engage this knowledge in multiple forms of representations that are best suited to the design task at hand. Nevertheless, the polymorphic diagram is especially targeted at the conceptual design workflow with an emphasis on spatial reasoning and configuration. Accordingly, it is based on an entirely different implementation when it comes to interfacing with the underlying information model. Broadly speaking, this difference manifests in both interaction and representation. Unlike existing BIM systems, where designers typically interact with discrete representations of building components (such as walls, columns, slabs, etc), the polymorphic diagram gives focus to spatial considerations represented through a simplified abstract notation. This abstract notation is inspired by bubble and blocking diagrams. Such diagrams are important cognitive and developmental mediums with wide applications in conceptual design thinking and spatial reasoning.
3. Objectives and method

The conception and development of the polymorphic diagram fits within a larger research project. The primary objective revolves around investigating how digital design media can support spatial thinking during the conceptual design phase. The discussion below presents an empirical study undertaken to help shed light on how digital design media can support spatial thinking. In particular, it looks at how offering multiple forms of conceptual representations can possibly enhance architects’ ability to configure space and its topological relationships. The experiment is abstract in nature. In other words, it is not meant to carry out the design of a particular space or building typology. Instead, it was intended to work with an important yet abstract concept of space: space adjacency.

The experiment itself involves configuring a set of blocks to fit given boundary conditions. The configuration of these blocks is to follow a set of generative spatial patterns while avoiding a set of degenerative ones. The notion of spatial order was developed to measure the success and positive arrangement of the blocks’ configuration. A stronger accommodation and accordance with these patterns yields a higher spatial order. On the other hand, evidence of degenerative patterns lessens the overall spatial order. It should be emphasized that what is of interest here is how designers examine and negotiate these spatial patterns. More specifically, the study hopes to investigate how moving between different representations modalities can improve the designers’ capability in configuring these blocks in light of these spatial patterns. To investigate this capacity, four advanced architecture students were asked to participate in this study.

The experiment was carried out in two phases. Participants are presented with boundary conditions along with a set of blocks that may differ in both size and color. The participants are then asked to configure the blocks to fit the given boundary conditions with the objective of maximizing the spatial order. In the first phase, participants proceed with the space configuration exercise using only one representation modality: the blocking representation. The participants attempt to configure the blocks to achieve the highest possible spatial order. To bring to light the potential value of multiple forms of representations in spatial thinking, the configuration exercise is carried out again. Phase two, however, involves selecting two participants (referred to as Group B). This group is to be supported with a second representation mode: the graph representation.

It was hypothesized that using multiple forms of representations will improve participants’ capacity to reason about space, achieving improved spatial order in this experiment. That is to say, with the use of a second rep-
resentational mode, participants belonging to Group B achieve a spatial order for their configuration that exceeds both Group B’s initial attempts and that of Group A’s second attempt.

Before discussing the results of this experiment, it is important to further elaborate on the concept of spatial patterns as they relate to this study. In particular, what is meant by spatial patterns, and how do they influence — either positively or negatively — the spatial order of the configured blocks?

3.1. SPATIAL PATTERNS

The notion of a spatial pattern here refers to an abstract construct used to represent and manipulate established concepts of space such as space adjacency, distribution, clustering, stacking, etc. In this early experiment, emphasis is placed on space adjacency. Representing this spatial concept was achieved through defining structures of relationships in terms of block properties. There are three block properties that form the basis of defining spatial patterns: size, color, and linkage. Both generative and degenerative patterns are derived from some logical combination of these properties.

Block properties and their variations are used to enable a wide variety of spatial elements. These properties include size, color, and linkage. There are four block sizes: 1, 4, 9, and 16. The unit value for a given block is, basically, the square root of its actual size. Color is used to distinguish between classes of space, three in total — two serviced spaces colored green and orange and one service space denoted with a gray color. Links represent a graphical notation used to determine the linkage between two adjacent blocks — whether linkage exists and, if it does, in what direction?

Spatial patterns could be realized in one of two modes: generatively or degeneratively. A designer’s ability to achieve a positive configuration of the blocks is contingent on articulating relationships between the different space enti-
ties in accordance with a list of generative specifications while avoiding degenerative ones. Again, the specifications underlying the generative and degenerative patterns are abstract. They are not designed to particularly suit or address actual space planning situations. Nevertheless, they are established to help study and shed some light on how designers negotiate spatial properties and how working with different forms of representations can assist the architects in carrying out this important design workflow.

Before going over the spatial patterns, however, consider these conditions and general rules governing block linkage.

- Each block has a number of links equal to its unit value. These links can be interactively moved around within the block itself based on the designer’s discretion.
- All links in a given block must be used. If a link is not used, it must be nullified. Users can nullify a total of 3 links per configuration.
- Links are used to establish linkage between two adjacent blocks. Two blocks are considered linked if they are adjacent and their links are aligned with one another.
- Each link has a direction of flow. The direction of the link flows always from the smaller block to the larger block.
- Void links indicate that blocks of similar color cannot use this particular link. Rather, to make use of that link, a block of a different color must be used.

3.2. SPATIAL PATTERNS

Space adjacency is a spatial pattern manifests in the quality or state of being adjacent, or of lying near contiguity. In any built environment, spaces are typically grouped in a manner that supports and achieves a more successful and appropriate operation. In the context of this experiment, this spatial concept has been simulated through defining desired situations for associating blocks together to achieve a positive (generative) application of this spatial pattern. Below is a list of generative situations. The degenerative situation for this spatial pattern is anything that negates or violates the situations listed below.

- AD1: Each block with a size greater than 1 has adjacent blocks whose collective value is equal to its size. However, exceeding the value is permitted if the block lies adjacent to the boundary line.
- AD2: Each block should be adjacent to a number of service blocks equal to its unit value. The remainder of the adjacent blocks (as determined by AD1) must be of the served space class.
- AD3: Green blocks have an additional adjacency criterion. In particular, these spatial elements must have more cells lying on the boundary of the configuration than otherwise.
3.2. SPATIAL PATTERNS

The notion of spatial order has been briefly presented above. It is a metric developed in this experiment to measure the success of a participant’s spatial arrangement. It can be determined as follows: Consider the different spatial patterns covered in the exercise (only adjacency, in this study). For each specification (see Section 3.1), evaluate its appropriate application. For each block in the configuration, placing it in accordance with the pattern’s specifications would earn units equal to the block’s value. On the other hand, each violation would deduct units equal to the block’s value. In addition to the pattern specifications, there are certain arrangements that would earn additional points. They can be used to further enhance the spatial order. These patterns include edge complete, edge sharing, edge surround, edge interlock, and edge inward.

Figure 2: Block adjacency. Situation (A) presents a generative adjacency pattern, while situation (B) and (C) present degenerative patterns. Specifically, situation (B) violates AD1, and situation (C) violates AD2.

Figure 3: Different situations to enhance spatial order for a given adjacency configuration. Different colors here are not indications of class difference. Instead, color is used to distinguish the blocks from one another.

Edge complete is achieved by situating support blocks on a single edge, as shown in Figure 3.a. Edge sharing is achieved by situating two blocks of
similar size but different classes such that they share an edge, as shown in Figure 3.b. Edge surround is achieved by surrounding a block with blocks of smaller size. Edge interlock involves two blocks of similar size but different classes. These blocks are offset by one cell where a block of size 1 is added to simulate the interlock. Edge inward is achieved by situating a block next to the boundary while pushing its links inward.

3.4 DIGITAL DESIGN ENVIRONMENT

The experiment is carried out using our prototype for a digital diagramming medium, one that supports the capacity to reason about space using multiple representation modalities. It was intended for the diagramming environment to provide a simple, almost austere environment to help designers focus on configuration tasks. In connection, special attention was directed toward interactively manipulating the blocks. Selecting, moving, and linking blocks were central issues throughout our development.

Besides its role in facilitating spatial thinking, the diagramming medium was developed to track designers’ moves and evaluate the spatial order manifest in their work. This analytical feedback technique was used to interpret and discuss participants’ results for this experiment.

![Figure 4: The experimental diagramming medium with multiple representation modalities.](image)

4. Experiment results

Each student participant produced two configurations. The spatial order for these configurations was determined based on the generative and degenerative specifications for the space adjacency pattern (see Section 3.1). Figure 5 depicts the spatial order for each spatial configuration. For each row in the figure, a participant’s first and second attempts are shown. Further to the right is an interpretation of the rate of spatial order improvement. The overall improvement rate measures how many more cells are in a generative state. On the other hand, the pattern-improvement rate measures how many more cells have been configured in desired generative pattern state, as explained
5. Discussion

From the results depicted in Figure 5, a basic observation can be made. In all of the space-configuration attempts, there was improvement in spatial order. That is, the spatial order in phase 2 is higher than that recorded in phase 1.

![Figure 5: Spatial order results for each of the experiment participants.](image)

In interpreting and analyzing the results, we looked at the rates of improvement recorded for the spatial configurations for both groups. It was found that the rate of improvement in the spatial order when using a second representational mode was significant, moving from 3% to 24%. This improvement
relates to the configuration results. But what about the configuration process itself? What is the effect of using a second representational mode?

In examining the feedback attained from the design environment, it can be said that the participants in Group A used a smaller number of moves to reach their block configuration. In a thirty-minute time period, Group A used 833 and 1002 moves, whereas Group B used 1197 and 1381, respectively. Working with multiple forms of representations will increase the number of moves used to negotiate and manipulate the spatial order.

Further examination of the moves reported by the experimental diagramming environment makes it clear that the designers in Group B used 483 and 601 moves in working with the graph environment, an average of about 39% of the total moves. These moves were used to establish relationships, as indicated and specified in Section 3.2. Participants then worked on working out these spatial patterns and relationships in space. On the other hand, Group A did not have the ability to build these relationships and use them as the basis for their spatial negotiations. Participants in Group A expressed that they had to use memory to work with these patterns and negotiate their situation. This is, perhaps, reflected in the significant increase in the number of blocking representation moves that they used.

![Figure 6: Number of space configuration moves used by Group A (P0,P1) and Group B (P2,P3).](image)

In light of the results attained from this experiment, the hypothesis of this paper was validated. That is to say, using a second representation modality indeed led to improved spatial order, a more successful and responsive space configuration.

6. Conclusion

Reasoning about space and its configuration lies at the center of the conceptual architectural design workflow. It is the architect’s mean of modeling
the design situation, bridging the gap between its problem definition and its emerging proposition. Paradoxically, however, modeling spatial information (knowledge about the design problem’s spatial requirements and its topological configuration) is the least well-developed feature in modern design systems. Moving forward, modern design systems must pay heed to this fundamental design faculty. It must extend its ability to assist architects in representing, manipulating, and evaluating spatial patterns and configurations. One of the key approaches in realizing this development revolves around bridging the gap between traditional and digital media. Specifically, this approach investigates the prospects for augmenting the cognitive traits of diagrams with layers of computation and information technology.

This paper presented and discussed the polymorphic diagram, a conceptual building information modeling environment. The scope of the paper focused especially on the role of representation in supporting spatial thinking during the conceptual design phase. The experiment presented in this paper has shown that designers’ capacity to reason about space configuration is improved when working with multiple forms of representation.

The importance of such findings has long been recognized in the literature on design studies. Nevertheless, the role of such findings and contributions in shaping modern design systems can hardly be traced. Admittedly, the experiment presented above involved a small number of participants. Hence, its results can hardly be generalized. Nevertheless, its value lies in hinting an important direction for future design technology development and contributes to its methods of implementation. It is hoped that such contributions from developing, the polymorphic diagram, would help shape design technology to complement and extend BIM’s important offerings to include modeling the design situation, especially its spatial requirements and its topological configuration.

References

Akin, O.: 1998, Cognition Based Computational Design Anniversary Celebration meeting of the Key Center for Design Computing, Australia, University of Sydney.