Using Design Strategy Maps to Chart the Knowledge Base of Climatic Design: Nested levels of spatial complexity

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ABSTRACT: This paper describes a portion of research to generate and test an integrated knowledge structure for net-zero energy design at the preliminary architectural design phase that helps designers choose families of design strategies. Its premises are that important relationships among energy topics can be expressed in architectural terms as associated design strategies and that a sequence of complexity can structure a map of important relationships among strategies at different scales. The ‘Design Strategy Maps’ generated here are a series of graphic diagrams organized into nine levels of complexity, from materials to neighborhoods, which show the relationships among design strategies in a nested, lattice-like network, with these characteristics: Each strategy is both a whole and a part; each organizes and is made up of smaller strategies, and also has a context within a larger strategy. More complex/larger strategies organize patterns of smaller ones. A full network of strategies is necessary for a whole and complete environment. The strengths of this organization lie in linking strategies across scales, identifying strategies potentially critical to the success of another, and providing a graphic overview of the whole knowledge base.

Keywords: climatic design, Design Strategy Maps, holarchy, scale, complexity, structural levels, net-zero energy, knowledge structure, design strategies, wholeness, holon, holarchy

INTRODUCTION

Designers conduct a timeless search for order in Nature and for how to align the order of human constructions within that order, which can bring forth beauty and inspiration. In doing so, several perspectives on the knowledge base of design, and of climatic design in particular have emerged. Design knowledge can be accessed in terms of scale, design components, typology, or energy issue, for example. Each way of ordering reveals or discloses and simultaneously conceals something that a different viewpoint does not. An individual designer’s learning style, temperament, design process, or worldview may dictate which approaches used seem best. None are necessarily better or worse, but works on climatic design or passive architecture show advantages and disadvantages. Some, such as Lechner [1] and Moore [2] use energy topics, such as heating, cooling and lighting, yet one of the primary drawbacks is that the relationships among the issues are occluded. In addition, these narrative-based approaches make identifying, naming, and selecting all but the most general classifications of strategies (toplight vs. sidelight, or the classic types of passive solar systems for example) quite challenging. Scales of design are mainly dealt with in a cursory way; in fact, many sources pay little attention to scales larger than a single building.

Brown, et al, in Inside/Out [3], used a matrix of phases of the design process and energy topics that was based less on modular knowledge and more on modular design procedures. Such matrix mapping is effective for identifying missing elements of a knowledge domain. Watson and Labs [4] used a matrix combining modes of heat transfer, such as conduction and radiation, and basic categories of architectural form, like solar walls and windbreaks. It was an early and influential collection of named, relatively modular knowledge-based strategies that connected engineering logics and design logics.

Brown [5], in Sun, Wind & Light: architectural design strategies (SWL), used three broad architectural scales (groups of buildings, buildings, and building parts) and a system of architectural elements. At the scale of ‘building groups,’ the elements were buildings, streets, and open spaces; at the scale of ‘buildings,’ rooms and courtyards; and, at the scale of ‘building parts,’ the elements were walls, floors, roofs, and windows. Design strategies at a scale were either single elements or combinations of elements. This approach was developed and expanded by Brown and DeKay [6], allowing the authors to emphasize the relationships among heating, cooling, and daylighting at the scale of particular design components, such as a window. For example, all of the design strategies for windows were grouped together, and if the designer’s concern that day was designing...
windows, everything in the book about windows was easily located on adjacent pages. The drawback to this organizational method was that if a designer was interested only in one issue, such as daylighting, considered across a range of scales and design components, it was difficult to find the applicable design strategies. In using SWL over the past decade with students and practicing architects, it became apparent that, while the strategies covered a large portion of the knowledge base, the relationships among strategies, and how they might be associated to create a passive-energy building, were poorly understood by users. To assemble a workable set of strategies without leaving out something important required significant experience.

RELEATIONSHP AMONG STRATEGIES

Mazria [7] used design patterns at different scales based on Alexander’s pattern language model [8]. Pattern languages, if clearly defined, have the potential to relate various patterns across a range of scales and topics. Both Alexander and Mazria embed relationships between patterns within the text, but these relationships are not mapped. Pattern language theory includes the idea of nested order, but scales or degrees of complexity remain unrevealed and attempts to map the pattern relationships have not used the nested complexity, leaving the user with a relatively tangled visual web. Alexander’s implied nested structure uses some of the basic premises of Systems Theory, such as the idea that systems occur at a series of interrelated scales, with similarities between levels of organization. Living systems are hierarchically organized and each system level is composed of component systems of lower levels and becomes a component system of the level above.

In a more general way than defined by Alexander, patterns are configurations of relationships. More specifically, design patterns are generalized solutions to recurring design situations, stated so that important criteria can be met while the specific solution can occur in thousands of unique ways. Both patterns of events and patterns of space are expressed in design patterns. Each design strategy in SWL establishes a configuration of relationships among formal elements, which define patterns of space. The SWL strategies also relate these patterns of space to a pattern of process having to do with heating, cooling, lighting, ventilation, power or human perception. The missing aspect has been the ability to visualize the connections among the many strategies.

A pattern language is the set of relationships and regularities among groups of patterns. The connective rules that define the language are as important as the patterns themselves. Salingaros [9] outlines in ‘The Structure of Pattern Languages’ the nature of the interconnections required to form a valid pattern language: “A pattern is an encapsulation of forces; a general solution to a problem. The ‘language’ combines the nodes together into an organizational framework. A loose collection of patterns is not a system, because it lacks connections.” He summarizes this as, ‘The language itself will be on the right track if it evolves a connective structure that incorporates scaling and hierarchy’ (Fig. 1) [9].

The Design Strategy Map concept proposed here is based on innovations from the project, “A New Knowledge Structure for Designing Net-Zero Energy Buildings,” a collaboration between the author and G. Z. Brown at the University of Oregon. The knowledge base used is from Sun, Wind, & Light, architectural design strategies (SWL) [6, 10]. The Design Strategy Maps, along with other results will be published in the forthcoming 3rd edition of SWL [10]. The relationships among patterns suggested in Figure 1 point to three goals of this work: 1) to identify the levels of hierarchy operating in the language system; 2) to better define the relationships among patterns at a given level in the hierarchy, and 3) to identify the order of more and less complex patterns and their relationships across levels. The design strategies in SWL can be considered a particular type of design pattern focused on energy performance, just as Alexander’s patterns are a particular type of pattern that are generally focused on social issues.

The structure of the Design Strategy Maps proposed here is based on observations about the relationships of parts and wholes first formally identified in systems theory and later in ecological hierarchy theory. Wilber [11] articulated the logics of multileveled (holarchic) systemic structures that apply to many knowledge domains in what he calls "the twenty tenets." DeKay developed an early version of the strategy mapping in studies of design strategies for green infrastructure [12]. In SWL, 2nd edition (SWL2) there are 109 analysis techniques and design strategies. This number is expanded in the 3rd edition (SWL3) to approximately 157. This expanding knowledge base suggests both the
development of the field and the inherently incomplete nature of any such attempt at mapping. Indeed the Design Strategy Maps technique itself revealed many holes in the SWL2 knowledge base, many of which have been addressed by new strategies in SWL3. The target of this knowledge base is climatic design and increasingly, net-zero energy design. SWL as a design resource focuses on the schematic and preliminary design phases of Table 1: Levels of Complexity for Design Strategy Maps

<table>
<thead>
<tr>
<th>LEVEL OF COMPLEXITY</th>
<th>DESIGN STRATEGY</th>
</tr>
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<tbody>
<tr>
<td>L10 Urban Quarter</td>
<td>Daylight envelopes</td>
</tr>
<tr>
<td>L11 City</td>
<td>Climatic envelopes</td>
</tr>
<tr>
<td>L12 Metro</td>
<td>Daylight envelope</td>
</tr>
<tr>
<td>L13 Region</td>
<td>Whole building</td>
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<tr>
<td>L9 Neighborhood</td>
<td>Room organizations</td>
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<tr>
<td>L8 Urban Fabric</td>
<td>Rooms</td>
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<tr>
<td>L7 Urban Elements</td>
<td>Building systems</td>
</tr>
<tr>
<td>L6 Whole Buildings</td>
<td>Window placement</td>
</tr>
<tr>
<td>L5 Room Organizations</td>
<td>Thin plan</td>
</tr>
<tr>
<td>L4 Individual Rooms</td>
<td>Sidelite room depth</td>
</tr>
<tr>
<td>L3 Building Systems</td>
<td>Window &amp; glass types</td>
</tr>
<tr>
<td>L2 Elements</td>
<td>Community of light</td>
</tr>
<tr>
<td>L1 Materials</td>
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architectural design; it therefore does not cover many of the more detailed decisions and strategies that are more appropriately considered in the design development or construction documents phases of the design process.

THE NESTED HIERARCHY OF THE MAPS
The Design Strategy Maps are one way to look at the structure of the knowledge base of net-zero energy design and climatic design. They show the relationships latent in the many design strategies in SWL3. They organize the design strategies into a nested, lattice-like hierarchical network. The organization of the Design Strategy Maps is based on the idea that each strategy is both a whole and a part. Each strategy organizes and is made up of strategies at a lower order of complexity and a smaller scale. Each strategy also has a context, which is another larger, more complex strategy. The second idea embodied in the Design Strategy Maps is that this nesting of strategies within strategies can be associated with levels of scale, where each larger scale exhibits an increase in complexity. The spectrum of complexity is organized in a system of thirteen levels, from materials to regions (Table 1). SWL3 currently addresses only nine of these levels. The 'Urban' levels 10-13 are beyond its present scope.

Using this logic of parts and wholes, an architectural Element [L2], such as a window, is made up of and cannot exist without its constituent Materials [L1], such as glass and wood. L2 Elements help to build larger, more complex strategies at the level of [L3] Building Systems, such as walls, roofs, and floors. In turn, [L3] Building Systems are configurations of [L2] Elements. Similarly, [L4] Individual Rooms are configurations of [L3] Building Systems; while [L5] Room Organizations are made up of [L4] Individual Rooms, and [L6] Whole Buildings are combinations of [L5] Room Organizations. Each increase in complexity proceeds in this way, a nested hierarchy of spatial order.

Of course, this is only one way to look at the order of parts and wholes. One could generate a system with more fine gradations or one with fewer levels. However, this is a system that seems to fit the common logics that designers use and how they think of formal building elements. It is about the simplest system of levels that accounts for all of the physical elements of design and how we can empirically observe parts combining to form larger patterns. The hypothesis of this ordering system is that these relationships among scales are necessary for a whole and complete built environment and that, in most cases, design strategies at several levels are needed for a particular design strategy to function and for the building as a system to work. Without this kind of scalar continuity of the strategies used in a building design, an entire architectural idea, such as the idea of “a building as a lighting fixture for daylight,” may break down and fail.

THE EXAMPLE OF DAYLIGHTING
One simplified route (there could be many) through the full hierarchy for a building and context designed for daylight is shown in Table 2. As an example, the
SIDELIGHT ROOM DEPTH [L4] strategy says that the depth of a room with windows on only one side should be no more than 2.5 times the height of the window head to achieve an acceptable ratio of light between the windows and the back of the room. If this pattern is extended to a consideration of a building plan, it generates in combination with other L4 strategies, such as DAYLIGHT ZONES, yet another strategy, THIN PLAN [L5]. By this strategy, the plan thickness of any part of a sideloaded building should not exceed 6–7 times the window head height (if an internal electrically lighted zone for circulation is allowed). Moving down in scale, SIDELIGHT ROOM DEPTH organizes and depends on the L3 strategies of ELECTRIC LIGHT ZONES and WINDOW PLACEMENT. In turn, WINDOW PLACEMENT is built on a set of strategies that includes DAYLIGHT APERTURES [L2] which depends on WINDOW AND GLASS TYPES [L1].

Moving up the levels of complexity, THIN PLAN [L5], contributes with other strategies to build DAYLIGHT BUILDING [L6], and when thin plan buildings are intersected with a city grid, they help form DAYLIGHT BLOCKS [L7], which in turn helps build a pattern of DAYLIGHT DENSITY [L8]. The NEIGHBORHOOD OF LIGHT strategy [L9], helps to organize the smaller strategies of DAYLIGHT DENSITY and CLIMATIC ENVELOPES. A successful daylight building in a context of daylight access will likely employ one or more of the SWL daylighting design strategies at each of these levels of complexity. Most often, there are several strategies available at each level. Of course, not every building will employ every possible strategy. Finally, it is clear that the collection of SWL strategies is incomplete and that knowledge base keeps expanding! Given that there are many daylighting design strategies not covered in SWL, such different strategies might also be substituted at a given level to achieve a whole solution.

**ANALYTIC AND CONTEXTUAL THINKING**

Form is often understood in architectural terms as the pattern that configures parts within the whole. Many, if not most, ways of understanding these formal patterns involve techniques of analysis that break down or dissect/deconstruct the larger whole into its constituent elements or their fundamental arrangements and relationships. The analytic method is a valid approach, from which we can learn much about buildings. It can be thought of as moving from higher to lower levels of complexity in the Design Strategy Map system. Analysis is true and correct in that it describes one portion or aspect of design, but analysis alone is incomplete and insufficient in two ways:

1) The emergent qualities unique to the whole are never found via analysis, which looks for only those qualities found in the parts.

2) Atomicstic analysis misses how the whole is simultaneously a part of something larger.

**HOLARCHIC STRUCTURE OF THE MAPS**

In architectural terms, we can think of a building’s form as both a product of its constituent parts, the internal 'order within' and at the same time, as a product of its external context-based order, the 'order without.' This logic applies at every scale of design. Instead of form alone, we can think of the more inclusive idea of 'form-in-context, which is a multi-tiered nesting including parts, wholes and contexts. Every whole at every level is made up of parts. Such things with their whole/part nature are known in systems theory as holons. A hierarchy of nested holons is a holarchy. In SWL the design strategies are treated as holons. The Design Strategy Maps are then a map of holarchic structure following a strict set of the following principles.

Consider for example two strategies, 'A' and 'B', as shown in Figure 2. In general, if 'STRATEGY A' is shown above 'STRATEGY B' in the Design Strategy Maps, then the following hypotheses are usually true, but not vice-versa.

- A is the whole of which B is a part.
- A helps to organize B or the pattern of Bs.
- A unfolds or contains or includes B.
- A is a context for B. B is nested within A.
- B can exist without A, but A can not exist without B (or some B as not all possible design strategies are identified in SWL3). So, if all the B s are destroyed,
A is also destroyed. A needs B (or at least one B) to exist.

- The character of A is the configuration of relationships between Bs. A is enhanced by B.
- A transcends but includes B.
- There are more Bs in the world than As.
- A is more complex than B.
- In design situations, B can participate in multiple As. For example, the elements at the complexity level of building systems [L3] are roofs, walls, floors, etc. These are organized at the next higher level as rooms [L4]. You can have walls without a room, but not a room without some combination of L3 elements, such as walls.

These are multiple ways to say the same thing. DESIGN STRATEGY A is then considered to be higher, more inclusive and deeper than DESIGN STRATEGY B. The principles above hold generally to be true in the author’s experience, although every variation of the list above may not seem to apply to an individual strategy. The Design Strategy Maps are an attempt to reveal the most significant relationships among the design strategies in Sun, Wind & Light, though more connections could, of course, be drawn and more strategies added.

**FORMAT AND SCOPE**

Figure 3 shows an excerpt from the Design Strategy Maps for the SUNSPACE [L3] passive solar heating design strategy and its constituent design strategies at two lower orders of complexity. Each graphic icon represents a design strategy in SWL, typically a 2-4 page spread with explanations, examples, and a design tool. The connecting lines indicate the A to B relationships already described. In theory, each design strategy is composed of at least two lower order design strategies; every design need not use all of the available strategies at a given level or even all of the connected strategies. The Design Strategy Maps therefore represent the potentially available language of strategies for a building. The Design Strategy Map for a particular building would be a smaller subset of designer-selected, related strategies.

The full set of Design Strategy Maps is too large to reproduce here and takes approximately six pages. Figure 4 shows the Design Strategy Map for the middle scale range of ‘buildings,’ covering levels of complexity from Whole Buildings [L6] to Room Organizations [L5] to individual Rooms [L4].
STRENGTHS AND WEAKNESSES
Each perspective on organizing design knowledge has some truth, some strengths and some weaknesses. The strengths of the Design Strategy Maps are in linking strategies across scales and in identifying strategies that may be critical to the success of another strategy, or upon which a given strategy may depend. Just as significantly, they also provide a graphic overview of the whole knowledge base. The weaknesses of the Design Strategy Maps may be that they are only really helpful if the designer already knows the essence of several strategies and can associate the icon with the knowledge of the design strategy that it represents. Therefore, they may be best for more advanced users and may seem somewhat opaque for beginners. Yet, the structure allows one to navigate from known design strategies to unfamiliar ones. The Design Strategy Maps also require users to understand the rules behind the graphics.

CONCLUSION
A substantial portion of architecture’s history is a search for order in the world, much of which reflects a concern for finding the order of Nature as understood in each time and expressing in form. We are connected to Nature when design’s experienced structural properties of order are aligned with the same structures found in Nature [13]. The structure of the built world is a medium of existence that embodies tacit knowledge and beliefs. We are connected to Nature when Nature’s flows, organized via design’s forms, are made visible, proclaimed, expressed, revealed and culturally voiced such that we become established in their knowledge as participating conscious members [13]. The Design Strategy Maps follow these same structural properties found in Nature, helping designers find and express this order, and ultimately, an integral expression of beauty.

We connect to Nature when design manifests ecological principles; one such means is by expressing holarchic order in design. As we have seen, in the systems view, Nature is composed of holons, systems that are both wholes and parts. Every design element is part of a larger whole, as is every building. This can be expressed as a series of nested scales in which each designed whole is understood as helping to build a larger whole. When ecosystems become the larger fabric of wholeness to which buildings contribute, then the holarchic structure of Nature can become a living structure of orientation.

The Design Strategy Maps reveal an underlying structure of buildings and suggest the possibility for a sustainable architecture integrated with climate and organizing the flows of energy at every level of complexity, from materials to cities. In one sense, Nature’s living systems are design’s holarchic contexts. In this way, Sustainable Design completes or participates in larger patterns of Nature. Expressing holarchic order is designing new human-Nature integrated context, inventing new wholes and contexts.

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