Connects and Disconnects Between Architectural and Engineering Design

This document summarizes informal comments I made at a meeting of the Danish Center for Integrated Design (DCID) held on 25 October 2000 at the Aarhus School of Architecture. DCID seeks new methods based on information technology to unify and integrate the architectural and engineering design.

I very much enjoyed my interactions with the DCID team, and was impressed with the high level of the discussion. I wish the team success in its continued efforts.

-Bob Haber

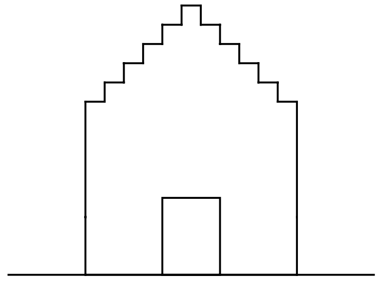
Ambiguity – good or bad? Different attitudes toward ambiguity and multiplicity of meaning distinguish the ways in which architects and engineers approach their work.

Engineers, particularly those with a mathematical bent, expend a great deal of effort to eliminate ambiguity from their terminology and methodology, so that problems and solutions can be communicated in a manner where there is only one possible interpretation. Problem statements with unique solutions are strongly preferred over those with multiple solutions. All this promotes safety and economy via reliable analyses and designs that can be executed in a predictable manner.

Architecture, on the other hand, is as much an art form as a technical discipline --- many practitioners would say more so. The tension and richness provided by ambiguity and multiple meanings is a hallmark of high-quality architectural design, just as it is in other art forms. For example, harmonic ambiguity in the form of dissonance is an important element in musical composition; a novel or play with characters that are either all good or purely evil is considered one-dimensional and uninteresting. Similarly, architects strive to create spaces and meaning in the built environment that can be interpreted in more than one way.

DCID team members need to keep in mind this fundamental difference between the two disciplines as they interact. In general, it is not possible --- or even desirable --- to reduce architectural objectives to deterministic engineering formulas. Nonetheless, interesting and non-trivial interactions between the disciplines are possible via computers, as demonstrated by the novel and stimulating work I witnessed at the meeting.

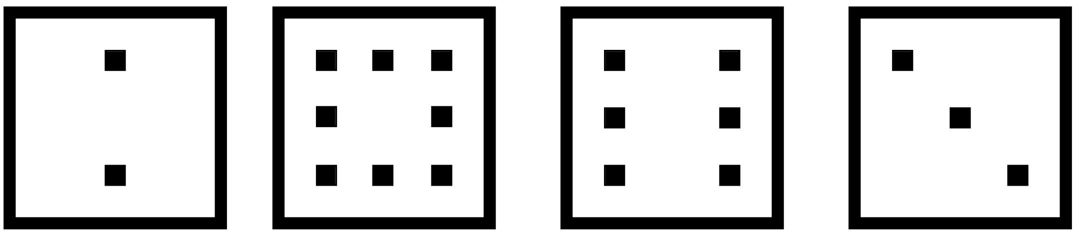
Abstraction and meaning: High-level abstraction and culture-dependent meaning are two elements of architectural design that are very difficult to encapsulate in computer-based design methodology. For example, the elevation below means “kirke” to a Dane, but has no special meaning in other parts of the world.



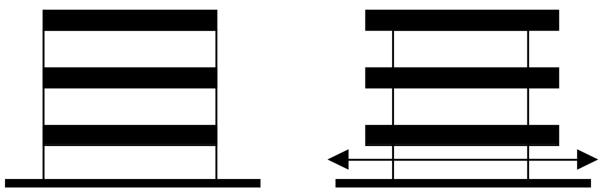
The process of formal abstraction that led to the modern interpretation of this idiom embodied in the Grundtvig church North of Copenhagen is an interesting aspect of the design process (that is also difficult to translate into an algorithm).

Interpretation of space and form: Architects often use *directionality* as a means to direct a visitor through a sequence of spaces. A more two-dimensional, graphical sense of directionality can also be used in the design of interior or exterior elevations. Although local edge/surface orientation does play some role in establishing a sense of direction, our perception of space and the order our brains attempt to impose on it is subtler and is non-local in nature.

For example, consider these plan studies of a square room that includes columns with a square cross section. Although the edges are in all cases equally divided between the horizontal and the vertical, we can emphasize the horizontal, the vertical or the diagonal, depending on the column arrangement. Our brain responds to implied connections between the columns, creating for example, a square within a square. Of course, our three-dimensional experience of the spaces these sketches depict would be quite different than the experience of viewing the 2D drawings. Nonetheless, the 2D drawings do give some sense of how our brains would interpret the orientation of the actual spaces.



The elevation of a building block is shown below. A stronger connection between interior and exterior space is established by pulling in the glass walls to create overhanging floor and roof slabs.



A reduction of the elements of architectural design to mathematical relations that can be used in computer optimization algorithms remains an ambitious, long-term objective (although not impossible in principle). Studies in perceptual psychology might be more revealing here than mining familiar image processing techniques. Global measures (as opposed to purely local measures such as edge orientation) will be required in the analysis.

Scale and hierarchy: Architects and engineers design with multiple length scales in mind; the motivations may overlap, but they can also differ. In the context of large-scale structures, both professions are likely to consider the gross concept of the structural system, and the design of individual elements and connections within the system. Architects also consider the aesthetic aspects of a building at different length scales. The largest scales might pertain to the appearance of a building from a great distance or how it relates to an urban setting, intermediate length scales pertain to views from the interior, and still smaller length scales that establish a connection to the human figure.

It would be interesting to develop computer-based design tools that implicitly recognize the need to design at multiple length scales. It is interesting to note that design for mechanical response at more than one length scale is an open issue in current research on topology optimization.

Two-dimensions vs. three: For practical reasons, engineers and architects will often resort to two-dimensional design tools, although in both cases the ultimate goal is to analyze and design three-dimensional objects.

Architects may use two-dimensional plan and elevation studies to develop and present a design. Many important aspects of a building's design can be revealed by these projections, and architects are trained to visualize the three-dimensional object they depict. However, 2D renderings can also be misleading, so architects still feel the need to use models and computer visualization to understand the three-dimensional aspects of a design.

Engineers often use two-dimensional idealizations of the geometry and behavior of a three-dimensional structure to simplify and reduce the size of a mechanical analysis problem. When used properly, these simplified analysis models can often reveal the important aspects of a structure's mechanical response. However, some structural failures can be traced to an engineer's failure to recognize the differences between the 2D idealization and the true 3D response. Some structures can only be understood in three dimensions. For example, a dome's response cannot be fully understood in terms of the response of a planar arch.

Both sides of the DCID team need to understand and appreciate the purpose and limitations of the other discipline's two-dimensional design tools. In many cases, advances in information technology are reducing the dependence of each discipline on 2D representations, thereby reducing the severity of this problem.

Multi-stage design process: Architects and engineers both employ iterative multi-stage design procedures, starting with initial conceptual design and progressing to more detailed final design. Both disciplines share a need for design tools with data models and data structures that reflect this process. It should be possible to defer decisions and leave things fuzzy at the early stages, while filling in detail and specific decisions as the design process progresses. Most existing CAD tools are not very responsive to this need.

Differences between the two domains should also be noted. For example, conceptual design for an architect can be very abstract, with content that might be more poetic than geometric. Conceptual design for a structural engineer tends to be more concrete in nature --- the choice between an arch and a suspension structure, between concrete or steel. Still, these differences tend to vanish in some of the most successful examples of integrated architectural and engineering design. For example, biological precedents for structure might also inform the more poetic aspects of conceptual architectural design.

Influence of the design medium on the design: It's interesting to consider the impact of computer-based design tools on the product of the design process. Historically, the media used in conventional design processes do seem to have an impact on the design result. For example, the absence of fine detail and the fluid, free-form shapes in the architecture of Eric Mendelsohn seems to reflect his use of quick charcoal sketches in his design process, just as the technical drafting style favored by Ludwig Mies van der Rohe is mirrored in the precise details and industrial appearance of his architecture.

How does the choice of a computer-aided design tool impact the design process? Does a designer working with a system based on constructive solid geometry end up with a different sort of design than one working with a spline model? Can different geometric modeling methods be combined in a well-integrated design environment?

Supremacy of structure vs. other design issues: Structural design is only one of many design issues that architects must respond to. Typically, other considerations impose sufficient constraints to eliminate highly optimized structural systems. The exception is in high-rise or long-span buildings, where structural considerations tend to dominate and play an important role even in conceptual architectural design.

Since the engineers involved in DCID are leading experts in structural optimization and can provide software systems for this purpose, it probably makes sense to focus on architectural design problems where the structure is a dominant issue.

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