Bridging the gap between design intuition and computation

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Abstract . *The paper examines the process of articulation and development of design concepts from a computational standpoint. The context of the research is the architectural studio and specifically the process of designing from scratch. The scope of the research is educational. Shape grammar formalism is used in the paper, to show how the concept of "porosity" was used by architect Steven Holl and his team in designing the 350-unit student residence Simmons Hall at MIT.*

Precedents "I depend entirely on concept diagrams, I consider them my secret weapon. They allow me to move afresh from one project to the next, from one site to the next." (Holl, 2002, page 73).

Steven Holl acknowledges his dependence on open-ended conceptual frames rather than on the existing building morphologies and typologies. Even though designers do not make a sharp distinction between the process of production and the process of interpretation of designs, an "intended" interpretation usually guides their actions in the studio. Early conceptual frameworks are used to frame some design approach. The role of conceptual frameworks in design has been the research topic of designers, engineers, and AI theorists.

Ullman (1992) examines the formation of conceptual frameworks in designing or re-designing in the context of mechanical engineering. Key feature of Ullman's approach is the generation of multiple concepts for the same design task, in two steps: a) functional decomposition and b) concept generation from functions. Functional decomposition involves breaking down the needed function as finely as possible, and with as few assumptions about form as possible. Concept generation involves listing conceptual ideas for each function, which come from the designer's own expertise, reference books, brainstorming etc. Schön (1963) proposes the displacement of concepts as a principle that explains innovation. Schön's approach is that old concepts can be used as a projective model for new situations: they can be transformed, or simply transposed to new contexts. Gero (1998) draws examples from the genetic engineering of evolutionary systems to show that design concepts are based on the emergence of patterns in the available design representations. Key feature of Gero's approach is that the observed patterns form the basis of concepts, which then can be memorized to become available for future use.

Objectives Presented is a paradigm of how a design concept set forth at the early stage of the design process can take generative expression: it can be converted into a system of production rules to produce designs. The production rules are expressed by the means of shape grammar formalism. The presented paradigm demonstrates how porosity a concept transferred from medicine, biology and organic chemistry, was implemented by architect Holl and his team in designing the 350-unit student residence Simmons Hall at MIT. It is suggested that a design concept is at its root a course of action meant to be performed by designers in the studio. Design concepts can be enhanced by formal-generative means, in three ways: First, by describing them in an explicit way; second, by leading to the implementation of computational devices with strong generative capacity; and third, by making them available for future reference. The descriptive task involves the mapping of the actions introduced by a design concept with the aid of rule schemata and rules. The productive task involves their implementation in shape grammars and computer programs. The reference task involves the assemblage of data structures that can be retrieved by future users.

Design concepts can help to bridge the gap between design intuition and computation. Against the temptation of "developing a computer program first, and then see what happens" a conceptual framework can assist in framing possible search spaces. This is important in architectural design, where the isolation between abstract problem solving methods and case-specific problems cannot be as clear as in other branches of engineering. Intuitions about associations with often ill-defined, but familiar concepts, have to be consulted frequently to assure that one is not dealing with fake issues.

Methodology Designers proceed from hypotheses, tentative constructions, which they gradually convert into pragmatic ones. The introduction of a design hypothesis is associated with the use of design concepts. A design concept can be defined "contextually" by a list of synonyms that explain it. This definition/explanation involves re-interpretation and may suggest new meanings. The progression from tentative constructions to case specific results is analogous to moving from general rule schemata to rules. Rule schemata are general syntactic statements with an empty class of premises, able to introduce rules. The expression, $g(x) \rightarrow g(y)$ denotes the rule schema, $(\forall x)\ (\forall y)\ g(x) \rightarrow g(y)$. Rule schemata determine rules each time the variables x, y are substituted by specific instances. A predicate g is used to specify the attributes of x and y. As shown in Stiny (2006), a shape rule schema applies on some instance C of a shape in two steps: First, a transformation t matches some part of C geometrically similar to the shape g(x), which appears on the left side of the rule schema. Second, the same transformation t is used to subtract g(x) from C and to add g(y), which appears on the right side of the rule schema, in its place. Concisely, $C' = [C - t(g(x))] + t(g(y))$.

The Porosity Paradigm Pore (from Greek π□ρος) means "a minute opening". Porosity or "the state of being porous" in organic chemistry and the study of plants and animals indicates the existence of small openings. In biology, in medicine and in organic chemistry porosity is defined as: "the attribute of an organic body to have a large number of small openings and passages that allow matter to pass through". The forms, sizes and distribution of pores are arbitrary. Their functionality is associated with circulation and filtration with respect to the external environment. Porosity was re-interpreted at Holl's studio, to guide the production of a sponge-like building morphology for Simmons Hall student dormitory, a 350 bed residence 10 stories high and 382 feet long. The synonyms used by Holl's team in the contextual definition of porosity form *(Table 1).*

Table 1: Contextual definition of porosity by Steven Holl Architects, NY

porosity	
porous, permeable	honeycomb
screen, net	riddle, sponge
pore	opening, hole
aperture, passageway	cribiformity
sieve-like, sieve	pervious
unrestricted	

Holl's definition of porosity was part of the "permeability hypothesis", stating that a porous morphology would produce positive effects at an urban and building scale, i.e. better air and light circulation, better accessibility and visibility at an urban scale, and better communication between interior and exterior spaces at a building scale. Holl (2000) recalls: "Our project began by rejecting an urban plan that called for a wall of brick buildings of a particular 'Boston type'. Instead, we argued for urban porosity". At the early stages the architectural team developed a series of design alternatives characterized by various types and degrees of "permeability". "Overall porosity" was introduced by a set of productive operations the results of which were captured in sketches and models. A small fraction of these appears in *(Figure 1)*

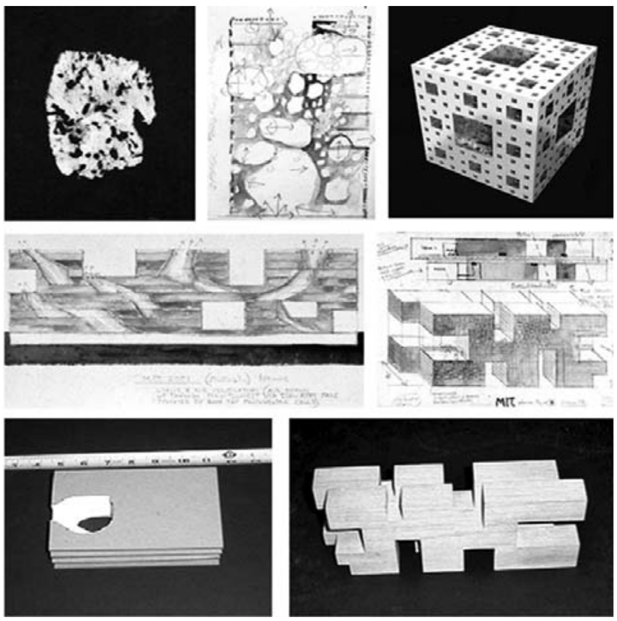
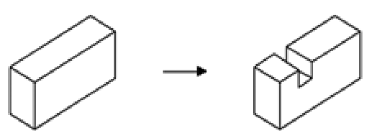
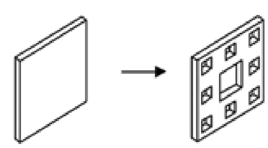
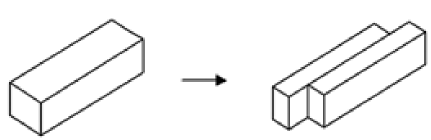
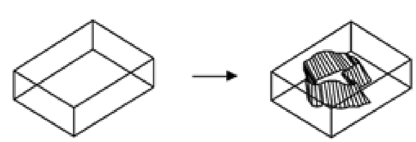


Figure 1 . Overall porosity. Illustrations by Steven Holl Architects NY

The productive steps performed by Holl's design team included: (a) the assembling of a building container, and (b) the application of porosity operations that transformed the building container. Porosity was accomplished in four ways: First, by creating large-scale recesses of building mass; Second by creating protrusions of building mass; Third, by distributing a large number of windows of various shape and size on the elevations; Fourth, by distributing a number of cavities penetrating the building from top to bottom. The four operations can be expressed by four parametric rule schemata Α, Β, Γ, Δ. The rule schemata Α, Β, Γ are described in the algebra U33 that includes solids manipulated in 3-d space. Rule schema Δ is described in the product U13 x U33 including lines and solids manipulated in 3-d space.

Table 2: *Rule schemata* Α, Β, Γ, Δ.

porosity	
Rule schema A	Rule schema Γ
	
Rule schema B	Rule schema Δ
	

Rule Schema A, allows the creation of prismatic recesses of building mass. The operation exposes more building surfaces to the exterior and forms additional terraces. A rule schema is formed to express this operation: solids are subtracted from a larger solid. The participating solids are parametric oblongs and prisms. Rule the schema A affects the overall form and the square-footage of the building.

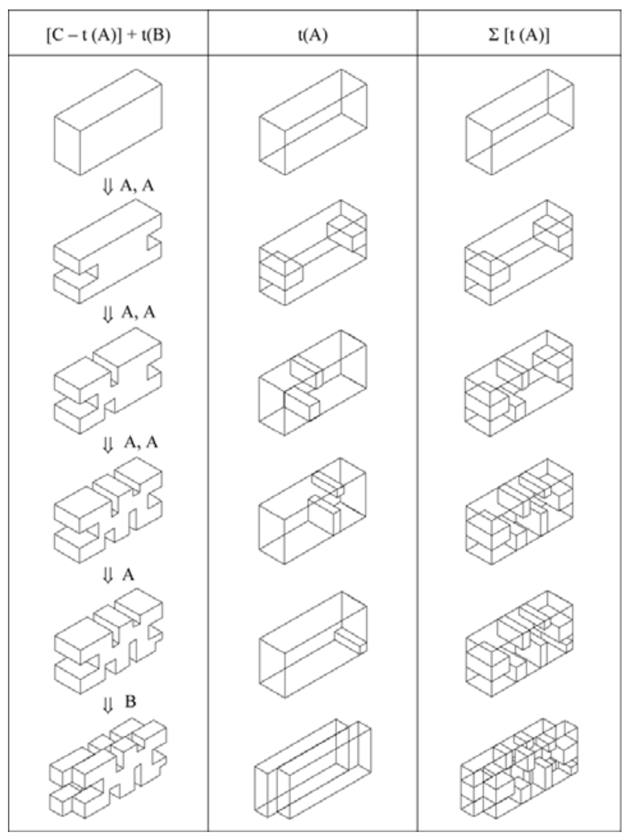
Rule Schema B, translates a building halve along its long axis. This transformation was labeled “diagonal porosity” by Holl’s team. The corresponding rule schema divides a parametric solid into two parametric solids. Then, one half is translated along its long axis, for some distance x. Rule schema B affects the form of the building without altering its square-footage.

Rule Schema Γ, is used for the treatment of the elevations. Multiple windows of various shapes and sizes are distributed on the facades. The analogous parametric rule schema applies on a parametric solid to produce multiple parametric voids through subtraction. The initial solid represents a concrete prefabricated panel. The voids are organized in a 3 x n orthogonal grid. Rule schema fi, affects the building facades.

Rule Schema Δ, was named “vertical porosity”. Vertical sponge-like openings penetrate the building from top to bottom allowing vertical circulation among different levels. Vertical porosity is described through a rule schema that pierces sponge-like openings on any two consecutive slabs. The rule schema also generates appropriate surfaces to bridge the consecutive openings. Rule schema Δ affects the square-footage and the form of the interior space.

A sample derivation involving rule schemata A and B appears in Table 3. The derivation is presented in three columns each including six steps performed in parallel. The main derivation appears on the left column. It is a series of subtractions among solids. The subtractions are performed in the algebra U33, which contains solids manipulated in 3-d space. At the top of the left column initial shape is a parametric solid representing the overall building. For brevity, the rule schema A is applied twice at the first three steps of the derivation. At each step, the left column shows the produced shape, namely: C’ = [C – t (A)] + t(B). The center column presents the subtracted solids t(A). The outline of the building is also presented with lines, for visual reference to the initial building volume. The product algebra U13xU33, which contains lines and solids manipulated in 3-d space, is used in this description. The right column presents the sum of the subtracted solids at each step Σ [t (A)], also in the product algebra U13 x U33.

Table 3 Porosity after rule schemata A, B.



Evidence of the application of the four design rule schemata Α, Β, Γ, Δ can be found at the early sketches, models and schematic illustrations of Simmons Hall. A possible design, emerging from the porosity concept appears next. The implementation of the building shows that the early conceptual decisions were partially or entirely reversed.

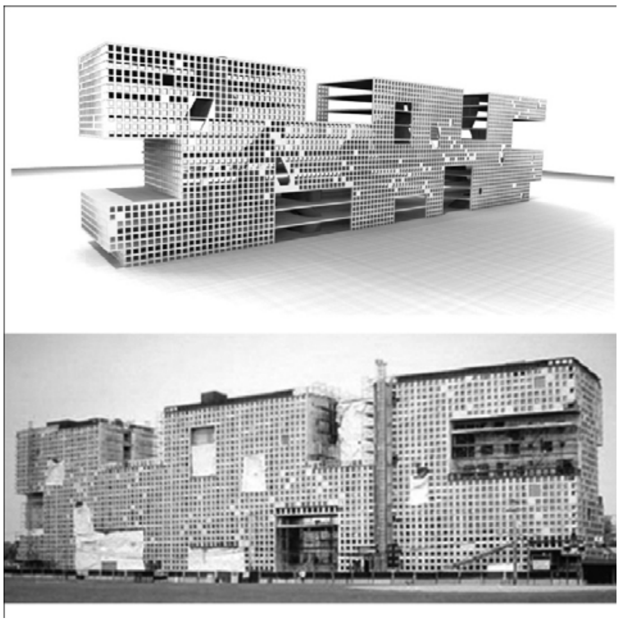


Figure 2 Possible and final implementation of Simmons Hall

The building recesses generated by the rule schema A were partially reversed. The results of the application of rule schema B (diagonal porosity), were entirely eliminated during design implementation. Several windows generated by the rule schema Γ, were ultimately blocked by concrete blocks, due to construction requirements. For the same reason, the variety of the window shapes on the facades was restricted. Further, the indented creation of multiple cavities, via rule schema Δ (vertical porosity) was hindered: Only three vertical cavities were distributed. Due to the fire-safety regulations, the vertical cavities were not allowed to penetrate the building from top to bottom, thus failing to fulfill their original functional purpose. Overall, the implementation of Simmons Hall differs from what was initially intended. But, the implemented design can be still produced by instances of the rule schemata Α, Γ, Δ.

Conclusions

For many designers the ability to diagnose problems and to formulate productive concepts and hypotheses plays a key role in the development of innovative design solutions. Even though designers do not sharply distinguish the process of production from the process of interpretation of designs, an "intended" interpretation usually guides their actions. A design concept is at its root a course of action meant to be performed by designers in the studio. Formal–generative means can enhance the productive contribution of design concepts, in three ways: First, by describing them in an explicit way; second, by leading to the implementation of computational devices with strong generative capacity; and third, by making them available for future reference.

Observation

Design concepts can become a significant aid in Computer Aided Design. They can help to bridge the gap between design intuition and computation. Against the common temptation of "developing a computer program first, and then see what happens", a conceptual framework can assist in framing some preferable search space. This is important in architectural design, where the isolation between abstract problem solving methods and case specific problems cannot be as clear as in other branches of engineering. Intuitions about associations with often ill-defined, but familiar concepts have to be consulted frequently to assure that one is not dealing with fake issues.

Acknowledgment

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Keywords

Production, interpretation, shape algebra, rule schema