Design concepts in architecture: the porosity paradigm

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Abstract: Presented is a paradigm of how a design concept can be converted into a system of production rules to generate designs. The rules are expressed by the means of shape grammar formalism. The paradigm demonstrates how *porosity* a concept transferred from biology, medicine and organic chemistry was implemented by architect Steven Holl and his team in designing the 350-unit student residence Simmons Hall at MIT. In the presentation, spatial algebras, rule schemata and shape rules are used to capture Holl's version of porosity.

1 Introduction

> "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 one of the most influential contemporary American architects, acknowledges his dependence on open-ended conceptual frames rather than on the existing building morphologies or typologies. The notion of a "*concept*" suggested by Holl coincides with the notion of "*design concept*" that is used in this paper. 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 architectural 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. In this presentation, spatial algebras, rule schemata and shape rules are used to capture Holl's tectonic-urban version of *porosity* by capturing the actions performed during the implementation of Simmons Hall. It is proposed that a design concept is, at its root, a course of action meant to be performed by designers in the studio. Novel aspect of the research is that demonstrates how design concepts can be treated by formal-generative means. It is shown that formal–generative methods provide an excellent medium for the articulation of design concepts: First, by describing them in an explicit way; second, by leading to the implementation of generative devices with strong productive 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 parametric rule schemata and rules. The productive task involves their implementation in shape grammars and/or computer programs. The reference task involves the retrospective assemblage of data structures for concepts, which can be retrievable by future users.

The combination of computational rules and machine readable conceptual frameworks could provide the foundation for systems that structure and store design information in more intelligent ways. Connecting the rules and frameworks to web databases can ease machine-to-machine communication. The Simmons Hall paradigm shows that in architecture, conceptual frameworks may be composites involving notions from various domains of inquiry, extraneous to design. The ability to share such frameworks over the internet would allow to store meaningful associations for them and to provide answers relevant to the set of the design rules that may imply. It would also allow the extraction of conceptual information from existing rules, by allowing the meaningful association of large rule sets.

2 Background

Concepts play a key role in the development of innovative design solutions for many architects and engineers. Even though there is no sharp distinction between the process of production and the process of interpretation of designs, an "intended" interpretation usually guides the actions of the designers. Concepts are used to frame some general design approach. Design concept formation has been the research topic of many engineers, and theorists. An overview of five representative studies follows.

Ullman (1992) examines design concept formation in designing or redesigning devices with specific functionality, within 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 of a device as finely as possible, and with as few assumptions about form as possible. Concept generation involves listing conceptual ideas for each function. Conceptual ideas come from the designer's own expertise, enhanced through patent searches, 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. In Schön (1990) the author examines the design process as a situated activity during which designers seek to solve a problem. The conceptual task of a designer is to frame the problem. For this purpose the designer initiates a reflective conversation involving action and reflection on the consequences. This reflective, bi-directional process, leads to the formation of new meanings and to the reframing of the problems.

Gero (1998) draws examples from the genetic engineering of evolutionary systems to show that design concept formation is 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 can be memorized and remain available for future use.

Finally, Richards et al. (2007) presents an analysis on the use of frameworks in electrical engineering, with the goal to identify practices to improve the development of systems. Three are the key issues of this discussion: the important role of artifacts in system design, the benefits provided by frameworks and the measures-of-effectiveness for assessing the value of frameworks.

Like Schön and Gero, this research focuses on creative design and not on re-design. Further, the focus is on architectural design as opposed to design in mechanical or system engineering. The motivation for the research stems from the observation that architects use conceptual frameworks that do not necessarily derive from a specific design setting. Concepts from domains extraneous to design are used as well. The paradigm demonstrates how the concept of *porosity* was redefined by architect Holl in a new tectonic/urban context. In this retrospective presentation, formal devices such as shape algebras and rule schemata are employed to capture Holl's tectonic version of *porosity*. A comprehensive analysis of shape formalism exists in Stiny (2006), and a discussion on the creative/expressive character of spatial rule systems exists in Knight (2005).

3 Concepts and rules

In the absence of standard pre-organizing design principles, designers base their search on tentative constructions, or hypotheses[1], which they gradually convert into pragmatic ones. Unlike a scientific hypothesis, which aims at being predictive (predict *all* future occurrences of a phenomenon) a design hypothesis aims at being productive: it aims to produce *at least one* successful solution in response to a problem. Hypotheses are associated with the introduction of concepts. While scientists introduce concepts with predictive capacity, designers introduce productive concepts. A concept singles out a property, a relation, or a function we intuitively understand by setting out a name, or a scheme. Concept definition obtains the form: _____ $=_{Df}$ _____ , where $=_{Df}$ can be read "*is*". The left void is occupied by some term and the right by a known expression. For example: Pore $=_{Df}$ minute opening.

Instead of providing a straightforward definition like the previous, a design concept is usually defined "contextually", by a list of synonyms that explain it. This type of contextual definition involves re-interpretation and may suggest new meanings.

The formal analogous of progressing from tentative constructions to specific results is to move from general rule schemata to rules and their parameters. Formal systems make use of general syntactic statements when it becomes necessary to state potentially infinite rules. Such statements are rules with an empty class of premises able to introduce other 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 syntactical 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, $C' = [C - t(g(x))] + t(g(y))$.

[1] Hypothesis: "A*n interpretation of a practical situation or condition taken as the ground for action; or, a tentative assumption made in order to draw out and test its empirical consequences*" (Merriam-Webster dictionary).

4 Simmons Hall

The Simmons Hall dormitory belongs to a strip of potential new MIT buildings along Vassar Street, in Cambridge, Massachusetts. The strip forms the Vassar Street edge along the Briggs Athletic Field, and it is located next to the railroad tracks. The Simmons Hall is 350 bed residence 10 stories high, 382 feet long, providing amenities to students such as a 125-seat theater a night café and a restaurant with exit to the Vassar Street. Instead of the typical in Massachusetts urban brick wall model, the strip was envisioned by architect Holl and his architectural team, as a "porous" membrane.

During the process of designing Simmons Hall, the features of *pores* and porous materials were approached as tectonic possibilities. The design concept of *porosity* was imported from biology, medicine and organic chemistry to transform a "porous" morphology for Simmons Hall, via a series of design operations. Accordingly, the overall building mass of Simmons Hall was designed to have five large scale recesses, while a system of vertical cavities creates vertical porosity allowing light and air to circulate. Moreover, the building facades have a large number of operable sieve-like windows.

Figure 1. Simmons Hall student residence at MIT. Windows on the facades.

The material for this presentation emerged out of two meetings with the architect Steven Holl, and three interviews with the project architect Timothy Bade. Architects Steven Holl and Timothy Bade kindly allowed me to access the design material that was produced in their studio. The illustrations of the paper present some of this material: original sketches, working drawings and models from all the stages of the design process of Simmons Hall. The paper describes the design developments as these can be followed through the drawings and the models. The presentation is retrospective. Spatial algebras, rule schemata and production rules capture Holl's tectonic-urban version of *porosity* as this reveals itself though the evolution of the sketches and the models. The rules do not replicate the actual steps of the design process.

4.1 Porosity

Pore (from Greek *πόρος*) means "a minute opening". *Porosity* or "*the state of being porous*" in the context of organic chemistry and the study of plants and animals indicates the existence of small openings. In biology and in medicine *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, in order to be used in a new tectonic/urban context, to guide the production of a sponge-like building morphology. The use of the concept of *porosity* by Holl's team, reminds the principle of concept displacement, as described in Schön (1963). Holl (2000) notes: "*What if one aspect of a site – porosity – becomes a concept? We hope to develop the possibility of a collection of things held together in a new way where the 'horizon' is open and merges with both exterior and interior*". 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

p o r o s i t y	
porous, permeable	honeycomb
screen, net	riddle, sponge
pore	opening, hole
aperture, passageway	cribiformity
sieve-like, sieve	pervious
unrestricted	

Holl's contextual definition of *porosity* was part of the "permeability hypothesis" 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. The "permeability" hypothesis established new relationships among the facts provided by the building program.

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 of the design process the architectural team developed a series of design alternatives. Contrary to what may have been Ullman's suggestion (multiple concept generation), each of the case-study-designs produced by Holl's team was a demonstration of implementing multiple variations of one concept: *porosity*. The schematic variations included "horizontal", "vertical", "diagonal" and "overall" porosity alternatives, characterized by various types and degrees of "permeability". After the completion of the schematic proposals, many of the design alternatives were rejected by the building authority, for a variety of reasons. Then, the team shifted to the "sponge" example to implement what was called "overall urban porosity".

Overall porosity was introduced jointly with a set of productive design operations, which triggered the production of sketches and physical models. A small fraction of this production appears in the next Figure 2.

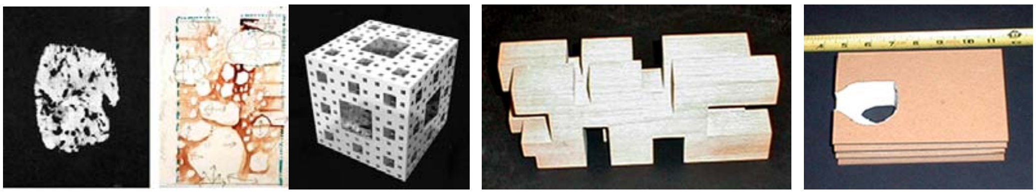
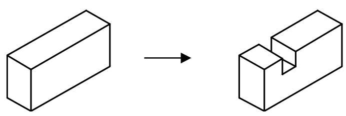
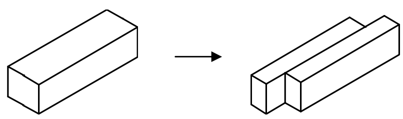
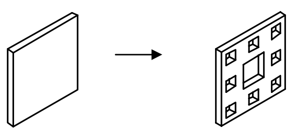
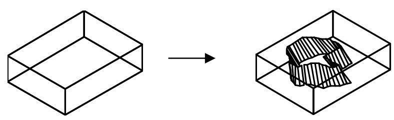


Figure 2. Overall porosity, by Steven Holl Architects, NY.

Roughly, the steps performed by Holl's design team included: (a) the assembling of a general solid container for the building, and (b) the application of porosity operations that transformed the building container. Porosity was implemented by bringing in contact as much of the building interior with the exterior as possible. The assembly of the building container was followed by the production of pores, openings, internal channels and cavities. 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 free-form cavities penetrating the building from top to bottom. The four operations can be expressed by four parametric rule schemata. A) prismatic voids are created by subtraction, B) protrusions are created by translation of a half solid along its long axis, Γ) sieve-like openings are applied on a solid, Δ) free forms are embedded on a Cartesian grid. The rule schemata A, B, Γ are described in the algebra U_{33} that includes solids manipulated in 3-d space. Rule schema Δ is described in the product U_{13} x U_{33} including lines and solids manipulated in 3-d space.

Table 2. Rule schemata A, B, Γ in the algebra U_{33}. Rule schema Δ in $U_{13}U_{33}$.

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

4.1.1 Rule schema A
The first operation allows the creation of prismatic recesses of building mass. It was labeled "horizontal porosity". The operation exposes more building surfaces to the exterior and forms additional terraces. A corresponding rule schema is formed to express this operation: solids are subtracted from a larger solid (in this case, the overall building solid). The participating solids are parametric oblongs and prisms. The application of rule the schema A affects the overall form and the square-footage of the building.

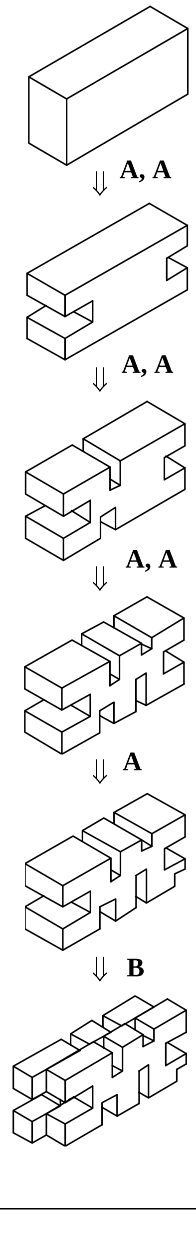
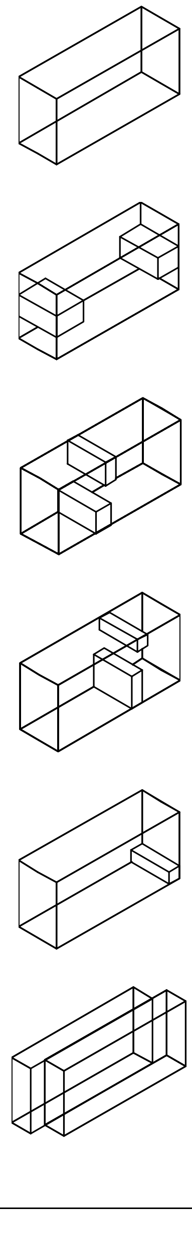
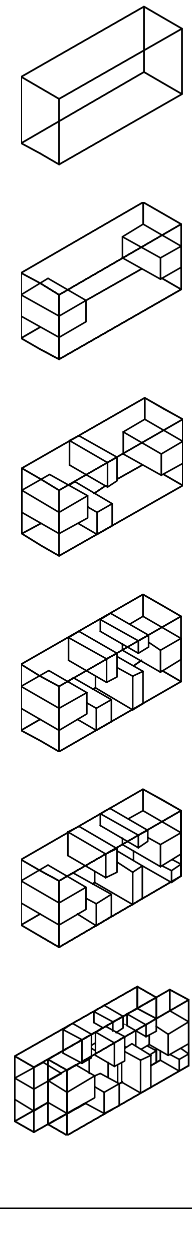
4.1.2 Rule schema B
The second operation translates a building halve along its long axis. This transformation was labeled "diagonal porosity" by Holl's team. The corresponding rule schema divides a parametric solid into two parametric solids. Then, one half is translated along its long axis, for some distance x. The result of this operation is that more of the building's interior is exposed towards the exterior. The application of the rule schema B affects the form of the building without altering its square-footage.

4.1.3 Rule schema Γ
A third operation 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. The application of the rule schema Γ, affects the facades without altering the square-footage of the building.

4.1.4 Rule schema Δ
A fourth operation introduced by Holl's team was named "vertical porosity". Vertical sponge-like openings penetrate the building from top to bottom allowing vertical circulation among the different building levels. Vertical porosity is described through a parametric rule schema that pierces sponge-like form openings on any two consecutive building slabs. The rule schema also generates appropriate surfaces to bridge the consecutive openings. The resulting framework of vertical cavities contributes to the circulation of air, light and people. The application of the rule schema Δ affects the building's available square-footage and volume, but also 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 parallel steps. The main derivation appears on the left column. It is a series of subtractions among solids. The subtractions are performed in the algebra U_{33}, 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 $U_{13}xU_{33}$, which contains lines and solids manipulated in 3-d space, is used in this description. The right column presents the total sum of the subtracted solids at each step $\Sigma\ [t\ (A)]$, also in the product algebra $U_{13} \times U_{33}$.

Table 3. Porosity at Simmons Hall, after applying rule schemata A and B.

[C – t (A)] + t(B)	t(A)	Σ [t (A)]
		

Evidence of the application of the four operations A, B, Γ, Δ can be found at the sketches, the drawings, the models and the schematic illustrations produced during the early design stages of Simmons Hall. One may notice that two different building systems coexist: the Cartesian grid, organized by the window and the plan grids, and the network of the free form, sponge-like, openings and cavities. Two illustrations of a possible design, emerging from the application of the porosity operations appears in Figure 3.

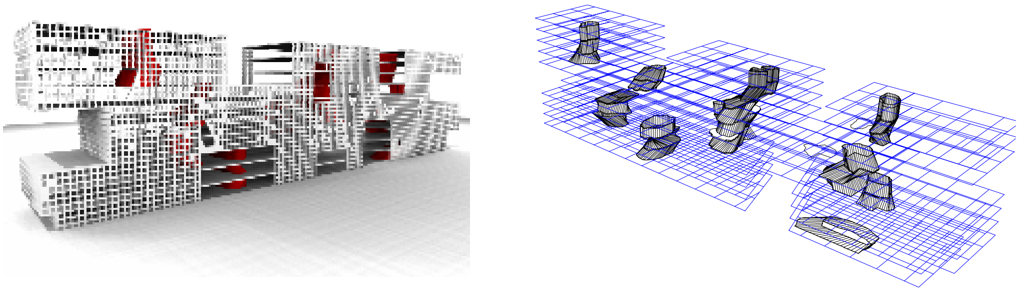


Figure 3. Two systems coexist: the Cartesian window-grid and the cavities (rule schemata Γ, Δ).

The implementation of the building shows that the early decisions were partially or entirely reversed at later stages.

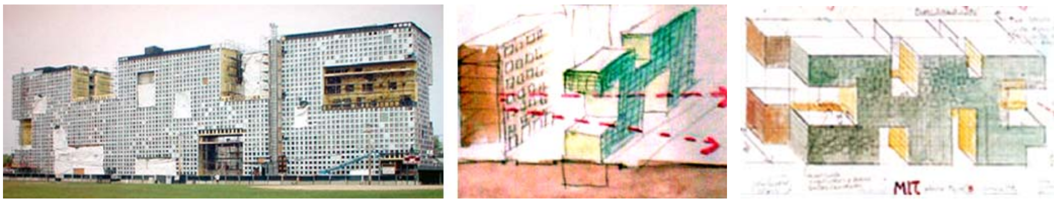


Figure 4. Simmons Hall (left). Early sketches (right). The implementation differs but remains within the conceptual framework. Illustrations by Steven Holl Architects, NY.

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 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 several cavities, via rule schema Δ (*vertical porosity*) was hindered: Only three vertical cavities were distributed in correspondence to the three student houses occupying the building. 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 Simmons Hall residence differs from what was initially intended. But, the building remains within the intended conceptual framework of porosity. The implemented design can be produced by variations or instances of the rule schemata A, Γ, Δ. The paradigm shows that rule schemata can model both the course of action and the necessary revisions that a design concept undergoes during implementation.

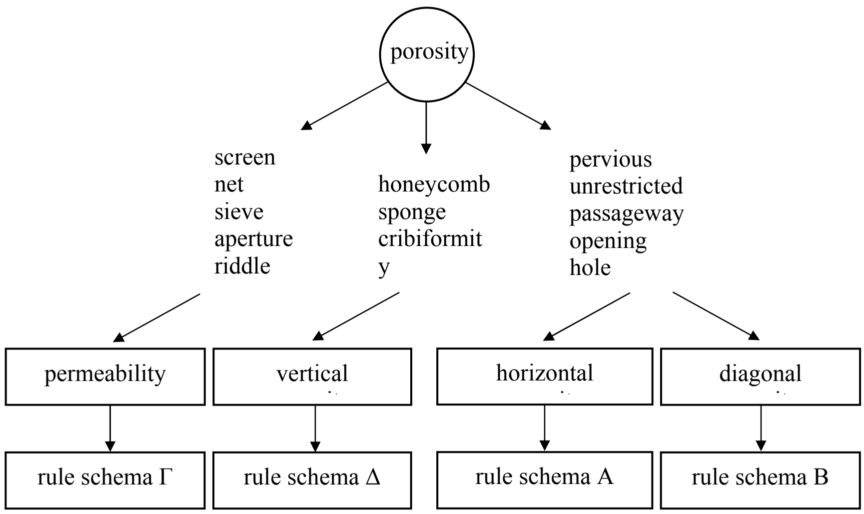
5 Sharing Conceptual Frameworks

Architectural design involves exchange of information within a diverse network of specialists who use a variety of applications, and produce a variety of artifacts. These artifacts may include physical objects, sketches, drawings and models, as well as computational objects, grammars, computer scripts, CAD models and finite element solutions. Richards et al. (2007) point out: "*The particular list of artifacts produced will vary from engineer to engineer, but all will agree that the production of these artifacts is a key step in the process from problem definition to engineered solution*". A current obstacle in this progress is that design information, in various formats, remains inaccessible by the different design collaborators. Most systems developed within specific branches of engineering adopt the conceptual frameworks of the particular branches, and they are not interoperable. The machine ability to share conceptual frameworks over the internet will greatly improve the exchange of information among different specialists.

In the Simmons Hall paradigm the notions of the computational rule and conceptual framework are employed to produce architectural designs. Computational rules are a standard expressive way to encode and reuse knowledge across multiple tasks. Rules are economic and effective in describing pre-conditions, post-conditions and relationships and in outlining processes and their products. Machine readable ontologies can be the platforms for sharing conceptual frameworks (ontologies). Rules in combination with machine readable ontologies, connected to the web, can provide higher level of conceptual abstraction and enhance machine-to-machine communication.

The Simmons Hall paradigm shows that in architecture, conceptual frameworks may be composites involving notions from various domains of inquiry. In the paradigm, the concept of *porosity* was transferred from medicine, biology and organic chemistry in a new tectonic/urban context. Nevertheless, conceptual frameworks have serious constructive implications for the design process. Table 4 shows how the concept *porosity* points to words and to actions (expressed by rule schemata).

Table 4. A framework for the concept of *porosity* as it was used at Simmons Hall



The conceptual framework of *porocity* and the related rule schemata lead to the production of certain kinds of artifacts (sketches, models, rules, computer scripts etc.), which form a coherent whole. They provide a base for setting broader objectives, they serve as mediums of communication, and they make possible the preservation and transfer of design knowledge, from one project to the next.

6 Conclusion

For many architects and designers the ability to diagnose design problems and to propose productive concepts and hypotheses play a key role in the development of innovative solutions in the studio. Conceptual descriptions set at the early stages of the design process are used to frame some general design approach. Design concepts are introduced contextually and in parallel to a course of productive design action that is described and explained in terms of them. Interpreting the output of the design action confers meaning on the concepts. This allows concepts and design artifacts to evolve in parallel. In design implementation, the existence of a conceptual framework allows necessary revisions to happen within a framework of original design intents. The paper proposes that formal–generative means can enhance the contribution of design concepts in the studio, 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 parametric rule schemata and production rules. The productive task involves their implementation in computational objects such as shape grammars and/or computer scripts. The reference task involves the retrospective assemblage of data structures which can be retrievable for future use.

The paper claims that conceptual frameworks are a significant aid in Computer Aided Design. Against the – common among architects – temptation of "*developing a computer program or script first, and then see what happens*", conceptual frameworks can assist in setting boundaries and framing reasonable objectives. They can also enhance communication among an extended network of collaborators and they can assist in preserving the accumulated design knowledge. All of the above are critical in architectural design, where the isolation between abstract problem solving methods and specific problems cannot be as clear as in other branches of engineering. Associations with often vague, but familiar concepts have to be consulted frequently, to assure that one is not dealing with artificial issues.

The semantic web could provide better foundation for systems that structure and store design information in more intelligent and flexible ways. The ability to share conceptual frameworks over the internet would allow to store meaningful associations and to provide answers relevant to the set of rules they may imply. It would also permit the extraction of information from existing rules by making possible the meaningful association of large rule sets. Finally, the semantic web would facilitate the development of design tools that improve the available design intelligence in an organic fashion, by extracting information from existing databases and by updating the available design intelligence.

Acknowledgement

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