David Butelmann Dujovne
School of Architecture
Pontificia Universidad Católica de Chile
El Comendador 1916, Providencia, Santiago, Chile
dbutelmann@gmail.com

Claudio Labarca Montoya
School of Architecture
Pontificia Universidad Católica de Chile.
El Comendador 1916, Providencia, Santiago, Chile
clabarca@uc.cl
From Design Concepts to Design Descriptions

Sotirios D. Kotsopoulos
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 the process of designing from scratch. The scope of the research is educational. Shape grammar formalism is used in a retrospective analysis, to show how the concept of “porosity” was used by architect Steven Holl and his team in designing Simmons Hall, a 350-unit student residence, at MIT.
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.” [1]

Architect Steven Holl acknowledges his dependence on open-ended conceptual frames rather than on the existing building morphologies and typologies. Holl disregards any fixed architectural vocabulary in favor of an “initial concept” capturing the essence of design possibilities that he considers unique for each project. For Holl, a concept more than just a verbally expressed idea sets a “manifold relation” among the site, the geometry, the program, the circumstance, the materials etc.

For many architects and designers, design concepts play a key role in the development of innovative design solutions. 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 schemes are used to frame a particular design approach. In this paper, a method for generating architectural form from design concepts is suggested. The method is based on visual productions rules that generate design descriptions. The production rules are expressed by means of shape grammar formalism. The presented paradigm is a retrospective demonstration of how porosity, a concept transferred from medicine, biology and organic chemistry, was used by architect Holl and his team in designing Simmons Hall, a 350-unit student residence, at the Massachusetts Institute of Technology.

The novel aspect of the paper is to show how a design concept can be treated by formal-generative means to produce design descriptions “from scratch”. Background assumption and motivation of this study was that a design concept is at its root a course of action meant to be performed by the designers in the studio. Setting a design concept is equal to distinguishing the identity of particular design events. It is proposed that there is no more to framing a design concept than there is to grasping a number of grammatical transformation rules. But, setting forth a design concept is not equal to laying down instructions. It depends on “framing ideas” of particular design activities and coping with spatial relations and their features. The paper shows that the productive contribution of early conceptual schemes in design can be enhanced by formal-generative means, in three ways: First, by making their description explicit; 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 implied by a design concept with the aid of rule schemata and rules. The productive task involves the implementation of the rules in shape grammars and computer programs. The reference task involves the assemblage of custom computational tools and data structures that can be retrieved by future
users. In extension of the above, it is proposed that design concepts can mediate between intuition and computation. Against the temptation of “developing a computer program first, and then see what happens”, a conceptual scheme assists in framing patterns of activity within a specific context. This is important in architectural design, where the distinction between abstract problem solving methods and case-specific techniques cannot be as concrete 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.

2. BACKGROUND

Engineers, design theorists, and researchers of Artificial Intelligence have thoroughly examined the use of concepts in design. David Ullman, for example, considers the formation of design concepts in the context of mechanical engineering, in designing or re-designing devices with specific functionality. In recent years, analogous views became increasingly popular among architects and designers. Ullman [2] defines a design concept as “an idea that is sufficiently developed to evaluate the principles that govern its behavior”. A key feature of Ullman’s approach is the generation and evaluation of multiple concepts for the same design task. Concept generation involves 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 happens through the listing of several conceptual ideas for each function. Conceptual ideas derive from the designer’s own expertise, enhanced through pattern search, reference books, brainstorming etc.

Donald Schön [3] proposes the displacement of concepts as a unifying principle in terms of which innovation in technical discovery and in theories may be explained as manifestation of a single process. Schön’s view evolves in relation to metaphor, analogy and comparison. The displacement of concepts has a “radical” character, in that old concepts can be used as a projective model for new situations and a “conservative” character, in that old assumptions may be transposed in a covert or non-critical way to fresh contexts. Schön [4] approaches design as a situated activity in which designers seek to comprehend and “frame” a problem. In their effort, the designers initiate a reflective conversation with the problem, 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.

John Gero examines the formation of design concepts in the making of design descriptions by means of computational models developed in Artificial Intelligence. Gero [5] uses implemented examples drawn from the genetic engineering of evolutionary systems to show that the formation of
design concepts is based on the emergence of patterns in the available design representations. A key feature of Gero’s approach is that the emergent patterns form the basis of new concepts: they are memorized to become a repertoire of known patterns that remain available for future use.

Along the same lines, Suwa, Gero, and Purcell [6] examine how early sketches are essential for the formation of design concepts. The researchers use protocol analysis in studying the design process of a practicing architect, to show that the early sketches serve as a record and as a provider of visual cues for association of non-visual information, but also as a physical setting in which design thoughts are constructed. The authors propose that the inspection of early sketches forms the basis for the invention of novel design issues. New concepts emerge out of inspection of the existing information, or as a result of action upon previously produced visual material. Novel design issues may include design goals derived from explicit knowledge, extensions of previous goals, goals aiming to resolve specific conflicts, or unsupported goals.

Like in Schön [3], [4], Gero [5], and Suwa, Gero and Purcell [6] the present study refers to creative design from “scratch”, as opposed to redesign. The focus is on architectural design, as opposed to design in mechanical engineering. Unlike Gero [5] and, Suwa, Gero and Purcell [6] this study is based on the observation that architects introduce concepts that do not necessarily emerge out of the existing design representations. On the contrary, they can be imports from domains foreign to design, like biology, chemistry, physics, mathematics, music, etc. Just as proposed in Schön [3], these concepts are transposed in a non-critical way to design contexts, with a view to focus the designers’ attention on particular features of a problem and to propagate a course of action. In this paper, shape formalism is used to model this action.

Shape formalism, as defined in Stiny and Gipps [7] and developed in consecutive papers, extends the formalism of production systems and generative grammars in modeling the interaction of spatial forms. Points, lines, planes and solids are classified in sets according to their spatial dimension, they are ordered with the part relation (≤) and they are organized into shape algebras, where operations like addition, subtraction and product can be used to perform spatial calculations. For example, the shape algebra U₁₁₂ contains 1-dimensional elements – lines – that are manipulated on the 2-dimensional plane.

Accordingly, the shape algebra U₁₁₃ contains lines that are manipulated in the 3-dimensional space and the shape algebra U₃₃ contains solids that are
manipulated in 3-dimensional space. Product algebras can be formed as combinations of shape algebras to provide more inclusive environments for calculation. For example, the product algebra $U_{13} \times U_{33}$ contains lines and solids, manipulated in 3-dimensional space.

Within the context of shape formalism, the spatial elements are composed with the aid of production rules. The rules can be used for computer implementation or to construct computational systems of generative and explanatory capacity known as shape grammars. A comprehensive presentation of shape formalism is presented in Stiny [8]. A discussion on the dual character (creative–expressive) of spatial rule systems can be found in Knight [9], while a discussion on how grammars may incorporate physical design-reasoning can be found in Sass [10]. Representative experiments in the use of rules in design synthesis can be found in Celani [11], Duarte [12], Kotsopoulos [13], and in Knight and Sass [14]. But, the strengths of formal composition have not been adequately explored in designing from “scratch”. This paper is an attempt to compensate this shortage. It shows how rules can be useful to describe the regular and productive early design processes and their suppositions.

3. METHODOLOGY

A design problem is described in terms of observation, past experience and on the basis of properties that are empirically ascertained. However, the scheme that provides the means to move from known to novel solutions cannot be contrived in terms of the existing representations alone. A designer has to provide new hypotheses that establish new productive connections among the available data and an interpretation for the network of their relationships. Hypotheses are employed in science and in design with different objectives at view. March [15] observes that a scientific hypothesis is of universal character: it seeks to predict all future occurrences of a phenomenon and to give account for its possible causes. A design hypothesis, on the contrary, is of existential character: it intends to produce at least one successful solution in response to a problem. Science aims at general laws while design at case specific results. Accordingly, a scientific hypothesis aims at being predictive while a design hypothesis at being productive.
Hypotheses are associated with the introduction of concepts. A concept singles out a property, a relation, or an action by setting out a name, or a scheme. For example:

Pore = minute opening.

A concept can be introduced contextually by a list of synonyms that explain it. The explanation becomes in this case a creative medium as it may suggest new meanings. Design concepts are introduced contextually and in parallel to a course of action that is organized and explained in terms of them. The meaning of a design concept becomes its use: interpreting the output of the action confers meaning on the concept.

The designers proceed from tentative constructions to definite ones. They make their way towards case specific results by gradually adapting their general conceptual schemes to the given contexts. This progression can obtain formal expression. Within a formal system, it is analogous to moving from rule schemata to rules. In general, a rule of the form \( x \rightarrow y \) denotes the action “\( x \) is substituted by \( y \)”. It specifies that provided a condition \( x \), a conclusion \( y \) is generated. That is, an objective is accomplished (\( y \) is produced) provided that a condition is satisfied (\( x \) is found). Table 1 shows how a subtraction of one prismatic solid from another can be expressed by a parametric rule in the shape algebra \( U_{33} \).

<table>
<thead>
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<th>rule expression</th>
<th>( x \rightarrow y )</th>
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<tr>
<td>rule condition</td>
<td>( x )</td>
</tr>
<tr>
<td>rule conclusion</td>
<td>( y )</td>
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When the rules of a formal system are potentially infinite it is impossible to state all of them one by one. Therefore, they are indicated by one or more syntactic statements. Such statements may be seen as rules with an empty class of premises that are able to introduce other rules. The expression \( (\forall x) (\forall y) g(x) \rightarrow g(y) \) denotes a rule schema. Rule schemata determine rules each time the variables \( x, y \) are substituted by specific instances. An assignment \( g \), determined by a predicate, states the attributes of \( x \) and \( y \) in a general way. In a rule referring to spatial forms the assignment \( g \) may specify a certain subclass of shapes, i.e.:

\( g: \text{“} x, y \text{ are prisms } \land \text{ the faces of } x, y \text{ are rectangles”} \)

The expression \( (\forall x) (\forall y) g(x) \rightarrow g(y) \) is noted \( g(x) \rightarrow g(y) \) or simply \( x \rightarrow y \), while the assignment \( g \) is usually provided as a short verbal description. Rule schemata are formal generalizations of rules. They specify a certain
treatment for an entire family of forms, instead of just for specific instances. For example, the shape rule illustrated in Table 1 becomes the expression of a rule schema after providing the above mentioned assignment $g$, which specifies a general family of shapes that this rule can apply.

Two are the key aspects of its application, “recognition” and “modification”. As shown in Stiny [8], a shape rule schema applies on a description $C$ in two steps: First, a transformation $t$ “recognizes” some part of $C$ geometrically similar to the shape $g(x)$. Second, the same transformation $t$ is used to “modify” $C$: it substitutes $t(g(x))$ with $t(g(y))$. Concisely: $C' = [C - t(g(x))] + t(g(y))$.

Figure 3. Example of applying the rule of Table 1, in the shape algebra $U_{33}$

Figure 4 presents a sequence of shapes produced after applying the rule schema of the Table 1, on an initial shape $C$, in the shape algebra $U_{33}$. Such a sequence of shapes is called a derivation.

Figure 4. Example of a possible derivation in the shape algebra $U_{33}$

When rules are used in the execution of predetermined tasks they are reduced to “instructions”. But, in the context of a non-deterministic design process rule setting is a creative activity. Setting rules is equal to identifying particular kinds of action, usually of repetitive character. This makes rules ideal for the framing of design concepts. There is no more to framing a design concept than there is to grasping a number of grammatical rules. Nevertheless, in the context of a non-deterministic design process possessing a number of rules is not equal to obeying to instructions. It requires dealing with relations and features. Lacking the ability to make relational judgments prevents one from understanding how something can be “part of” something else and makes the grasping of a rule, or a concept, impossible. First, “awareness” of what stands as a complete $x$ – that is, what we see on the left hand side of the rule, is required. Second, “judgment”, the ability to use one’s awareness of $x$, to distinguish a location to “match” $x$ in a display at a given time, is necessary. Since different matching locations are usually presented, judgment is required in distinguishing where and when
t(x) becomes part of C in an evolving design process. Third, coping with the recognition of matching locations that have the feature to be unfinished or incomplete xs – sets of maximal elements that can be embedded on it, without forming a complete x – is necessary. The recognition of incomplete xs emphasizes the distinction of a “characteristic pattern” from an arbitrary one. While any arbitrary x allows the recognition of individual instances t(x) in a description, an arbitrary x does not prompt the viewer to distinguish incomplete xs, which are not presented as wholes. On the contrary, a characteristic pattern – that is, a pattern singled out by name – provides better basis for the distinction of locations of incomplete matching. This observation allows for the distinction of places that have the feature to be parts of a characteristic pattern, and those which do not. Accordingly, a rule schema provides better means for treating incomplete xs, since it refers to a family of x-like forms rather than a specific x instance.

4. THE SIMMONS HALL PARADIGM

The Simmons Hall student dormitory is part of a strip of future buildings forming the Vassar Street edge along the Briggs Athletic Field at MIT, in Cambridge, Massachusetts. This strip of buildings was seen by Holl’s team as an opportunity to propose a new type of student living. Instead of the typical brick urban wall the strip was envisioned as a “porous membrane” including a number of individual dormitories, which function as the boundary of the residential city fabric. The dormitories were envisioned to be “permeable” to allow maximum visual penetration. At the same time, each dormitory was designed as “an individual house with a particular identity” [17]. Simmons Hall is a 350 bed residence, designed as a vertical slice of a city, 10 stories high and 382 feet long, including facilities such as a 125-seat theater and a night café. The corridors connecting the rooms were metaphorically approached by the designers as “streets”, operating as public places. In designing Simmons Hall, the features of “pores” and porous materials were approached as tectonic possibilities. The porosity concept formed a “porous” morphology through the application of a series of operations. Accordingly, the overall building mass has five large scale recesses, while a system of vertical sponge-form cavities creates vertical porosity, allowing natural light and air to circulate in the interior. The building facades are composed by 5538 operable windows.

▶ Figure 5. Erecting Simmons Hall student dormitory
The discussion of the Simmons Hall paradigm emerged out of three interviews with the project architect Timothy Bade, two meetings with the architect Steven Holl and a public lecture that Holl gave at Columbia University, in February 12, 2003. The illustrations include descriptions such as sketches, working drawings and models from the various stages of the design process. The presented visual material was also exhibited at the opening of Simmons Hall, in February 2003.

In the next section formal-generative methods are outlined that depict how the concept of “porosity” was transposed in a tectonic-urban context to guide the production of a sponge-like morphology for Simmons Hall. Parametric rule schemata are used to map the patterns of development in the working drawings and the models. The analysis is retrospective. The rule schemata aim at framing the design concept rather than describing the actual studio techniques. The adopted approach is favored for its explanatory and productive merits: it makes the design concept transparent by establishing links between “words” and “actions”, and it provides a basis for further computational exploration.

4.1. Porosity

Pore (from Greek πόρος) means “a minute opening”. Porosity or “the state of being porous” in medicine and the study of plants and animals indicates the existence of small openings. In biology 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, the sizes and the distribution of pores are arbitrary. Their functionality is associated with circulation and filtration with respect to the external environment. The concept of porosity was transposed in a tectonic/urban context to guide the production of a porous morphology for Simmons Hall. This brings into mind the principle of “concept displacement” as described in Schön [3]. Holl [16] mentions the influence of Marleau-Ponty stating that environments include patterns or “lines of force” and possibly meanings. Holl’s conceptual approach to design is addressed in his public talks [17]: “Within the phenomena of experience in a build construction, the organizing idea is a hidden thread connecting dispersed parts with exact intention”. More specifically, Holl [16] phrased the working hypothesis for Simmons Hall as follows: “What if one aspect of a site – porosity – becomes a concept? Porosity can be a new type of being… We hope to develop the possibility of a collection of things held together in a new way”. Table 2 presents the synonyms used by Holl’s team in organizing a contextual definition for porosity.
The porosity concept was part of a wider hypothesis, the “permeability hypothesis”, conjecturing that a porous morphology would have positive effects at an urban and building scale: better air and light circulation, better accessibility and visibility at an urban scale, and better communication between interior and exterior at a building scale. The permeability hypothesis helped the design team to establish novel relationships among the elements of the building program. Holl [16] 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 design team developed a series of design alternatives. Contrary to what is suggested in Ullman [2] – multiple concept generation and evaluation – each of the early case-study-designs developed by Holl’s team was a demonstration of implementing variations of the same conceptual scheme of “porosity”. The schematic variations included “horizontal”, “vertical”, “diagonal” and “overall” porosity alternatives, characterized by various types and degrees of “permeability”.

Some early schematic arrangements appear in Figure 6.

After many of the schematic proposals were rejected by the building authority, the design team shifted to the “sponge” example to implement what was labeled as “overall urban porosity”. Overall porosity was based on two general schemes: the abstract, recursive scheme of the Menger sponge and the organic scheme of the natural sponge (Figure 7, up-left). A tectonic version of porosity was realized by bringing in contact as much of the building’s interior with the exterior as possible, by creating openings, internal channels and cavities. This was accomplished in four ways: first, by creating large-scale recesses of building mass; second, by creating protrusions of building mass; third, by distributing multiple windows of various size on the elevations; and fourth, by distributing a number of free-form vertical cavities, penetrating the building from top to bottom. The four

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**Table 2: Contextual definition of the design concept of porosity by Steven Holl Architects, New York, NY**

<table>
<thead>
<tr>
<th><strong>porosity</strong></th>
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<tbody>
<tr>
<td>porous, permeable</td>
<td>honeycomb</td>
</tr>
<tr>
<td>screen, net</td>
<td>riddle, sponge</td>
</tr>
<tr>
<td>pore</td>
<td>opening, hole</td>
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<tr>
<td>aperture, passageway</td>
<td>cribiformity</td>
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<tr>
<td>sieve-like, sieve</td>
<td>pervious</td>
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<tr>
<td>unrestricted</td>
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**Figure 6. Building types of permeability. Steven Holl Architects, New York, NY**
operations guided the production of design descriptions. The results were depicted in sketches and models, a representative fraction of which appears in Figure 7.

The four design operations correspond to four parametric rule schemata A, B, Γ, Δ. The rule schemata A, B operate in the algebra $U_{33}$, which includes solids manipulated in 3-dimensional space. The rule schemata Γ, Δ operate in the product $U_{13} \times U_{33}$, which includes lines and solids manipulated in 3-dimensional space. The four design operations, described by the rule schemata, are: A) large-scale prismatic voids of building mass are produced through subtraction, B) large-scale protrusions are produced through division and translation of half of the building along its longitudinal axis, Γ) sieve-like windows are applied on the façade panels, through subtraction, Δ) vertical free, sponge like forms are embedded in the orthogonal building grid.

Illustrations of the four parametric rule schemata appear in Table 3.

<table>
<thead>
<tr>
<th>porosity</th>
<th>Rule schema A</th>
<th>Rule schema B</th>
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<tbody>
<tr>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
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</table>

Table 3: The parametric rule schemata A, B, Γ, Δ

Rule schema A

The first operation allows the creation of prismatic recesses of building mass. These are described by the design team as “large scale openings,
corresponding to main entrances, view corridors, and the main outdoor activity terraces of the dormitory”. The operation exposes more building surfaces towards the exterior and forms terraces. A rule schema depicts the operation: solids are subtracted from a larger solid, corresponding to the overall building mass. The solids are parametric oblongs and prisms. The application of rule schema A affects the form and the available square-footage of the building. The parametric rule schema A is repetitive: it applies several times under translation, rotation, reflection and scaling.

Rule Schema B

The second operation divides the building mass in two halves, and translates one along its longitudinal axis. The specific transformation was labeled by Holl’s team as “diagonal porosity”. The corresponding rule schema divides a parametric solid into two equal parametric solids and translates one half along its long axis, for some distance x. The result from the application of this operation is that more of the building’s interior is exposed towards the exterior. The application of rule schema B affects the building’s form without altering its square-footage. The parametric rule schema B is non repetitive: it applies only once under a single transformation, at the early stages of the design process.

Rule Schema Γ

A third operation is used for the treatment of the elevations, to distribute windows of various size. The operation has its conceptual basis in mathematics and the concept of the Sierpiński carpet, or its 3-dimentional extension the Menger sponge (Figure 7, up). The Sierpiński carpet is a 2-dimentional fractal constructed as follows: a) a plane, square in shape, is divided in $3 \times 3 = 9$ congruent squares, b) the center square is removed. This treatment applies recursively to the remaining 8 squares and it may continue indefinitely. A 3-dimentional version of the Sierpiński carpet, involving cubes instead of squares, forms the Menger sponge. Illustrations of Level 1, 2 and 3 Sierpiński carpets, appear in Figure 8.

In the context of designing Simmons Hall, rule schema Γ applies recursively on a square façade panel to produce multiple openings, through subtraction. Rule schema Γ introduces a mathematical expression of a “sponge”, which is based on the recursive construction of the Sierpiński carpet. This construction also responds to a need for better air and light circulation,
which was a core design concern in designing Simmons Hall. The application of rule schema Γ, affects the facades without altering the square-footage of the building. The parametric rule schema Γ, applies several times under translation and scaling.

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 circulation among the different levels. These are metaphorically described by the design team as “large dynamic openings… the lungs of the building, bringing natural light down and moving air up through the section”. Vertical porosity is depicted here by a parametric rule schema that embeds sponge-like forms within the grid of any two consecutive slabs. The rule schema Δ introduces free organic forms, which serve as a reminiscence of the natural sponge, as opposed to the more abstract, recursive formulations of the Menger sponge (Figure 7, up). The application of the rule schema Δ affects the building’s available area and volume, and the interior space. The parametric rule schema Δ applies several times under translation.

Derivation

A derivation involving the applications of the parametric rule schemata A and B appears in Table 4. The derivation is presented in three columns, each including six steps, performed in parallel. The main derivation appears on the left column involving a series of subtractions among solids. The subtractions are performed in the algebra $U_{33}$, which contains solids manipulated in 3-dimensional space. At the top of the left column, the initial shape is a parametric solid representing the overall building mass. For brevity, the rule schema A applies twice at the first three steps of the derivation. At each step, the left column shows the produced shape: $C' = [C - t(x)] + t(y)$. The center column, presents the subtracted solids $t(x)$ in the product algebra $U_{13} \times U_{33}$, which contains lines and solids manipulated in 3-dimensional space. The right column, presents the sum of the subtracted solids at each step $\Sigma[t(x)]$. The outline of the building is also presented with lines (for visual reference to the overall building mass).

A derivation involving the application of rule schema Δ appears in Table 5. The derivation is presented in two columns, top to bottom, starting from the left. It shows how the vertical, sponge-like cavities are embedded on the 3-dimensional orthogonal building grid. For brevity, the rule schema Δ applies more than once at all the twelve steps. The product algebra $U_{13} \times U_{33}$, which contains lines and solids manipulated in 3-dimensional space, is used in this derivation.
Table 4. Derivation of porosity after rule schemata A and B.

<table>
<thead>
<tr>
<th>[C – ι(x)] + ι(y)</th>
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Table 5. Derivation of porosity after rule schema $\Delta$. 

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Sotirios D. Kotsopoulos
A derivation involving the application of rule schema $\Gamma$ appears in Table 6. It presents the generation of perforated façade panels. The rule schema $\Gamma$ applies recursively on each individual panel to produce openings that are arranged in a $3n \times 3n$ (with $n = 1, 2, 3$) orthogonal grid. For brevity, the rule schema $\Gamma$ applies at once to all the panels of an elevation. The product algebra $U_{13} \times U_{33}$ is used in this derivation.

> Table 6. Derivation of porosity after rule schema $\Gamma$.

In the generation of perforated panels for the facades of Simmons Hall, the rule schema $\Gamma$ applies recursively on a concrete prefabricated panel to produce openings as presented in Figure 9.
Façade configurations involving panels like the above are depicted in early sketches of Simmons Hall. However, quickly the abstract concept of recursion gave its place to more tectonic considerations. In Simmons Hall, the exterior concrete wall serves as the main load bearing grid of the building. This dictates the standardization of the openings. The emergent component was the “perfcon”, a structure described by Holl’s team as “a design allowing maximum flexibility and interaction”. The building facades are designed to have a total of 5538 windows nested in a uniform concrete prefabricated wall 18” thick that fuses windows and structure. Early studies depicting the two design approaches appear in Figure 10.

The generation of a typical “perfcon” panel is depicted in Figure 11 by a rule of the form \( x \rightarrow y \).

A typical “perfcon” panel has three \( 2' \times 2' \) windows in height and six in width \((3 \times 6)\). Each individual room has nine windows in total \((3 \times 3)\). Therefore, typically, a perforated panel covers two adjacent rooms. However, there are \( 3 \times 5 \) panels and a small number of \( 3 \times 4, 3 \times 3, 3 \times 2, 3 \times 1 \) and \( 3 \times 7 \) panels. A schematic presentation of the full panel vocabulary appears in Figure 12.
The Figure 13 presents the parametric rule schema $\Gamma_1$, which captures the generation of openings on panels. The rule schema has the general form $x \rightarrow x - t(y)$. Three vertically aligned openings, are arranged in a $3 \times n$ grid (with $n = 1,2,\ldots,6$), while a standard panel-ending is applied to all panels on their left and right side.

Larger openings were applied in areas corresponding to lounges, while select windows were filled in, in areas which were critically overstressed. For the treatment of these two cases, two rule schemata are presented in Figure 14. Rule schema $\Gamma_2$ (left) unites a number of window openings into a single window opening. Rule schema $\Gamma_3$ (right) substitutes a window opening with a concrete block.

In the derivation of Table 7, the panels are generated at the first step using rule schema $\Gamma_1$. Large openings are applied at the second step using rule schema $\Gamma_2$, and the blocking of window openings, after rule schema $\Gamma_3$, ends the derivation. This derivation, in the algebra $U_{13} \times U_{33}$, does not capture the order of panel placement.

In the example of Figure 15, the rule schemata $\Gamma_1, \Gamma_2$ and $\Gamma_3$ apply on a pair of concrete panels to create and to block opening window openings.
Table 7. Derivation of porosity after rule schema $\Gamma$. 
The “perfcon” panels were used as building blocks in the erection of the facades: 291 panels were used in total, with approximately 11 panels erected per day. Due to the structural importance of the façade walls, the actual placement of the different panel types, and the number and size of their openings, were determined by structural and functional criteria. In a computational simulation of the principles that guided the panel placement, the discrimination of the various panel types can be expressed with the aid of labels, while the act of panel placement can be controlled with substitution rules. For example, at each floor: the typical $3 \times 6$ panels may get substituted first, the $3 \times 5$ panels next, the $3 \times 4$ next, etc., and the corner panels last. Of course, the determination of the position of each panel on a façade was the result of calculations that occurred in a much later stage of the design process. Accordingly, the formation of the appropriate computational rules, while taking into account these calculations, requires a level of detail that goes beyond the objectives of this discussion. An exposition of the necessary construction rules may follow in a future presentation.

4.2. Discussion

Evidence of the application of the four parametric rule schemata $A, B, \Gamma, \Delta$ can be traced at the early design representations, such as sketches, physical models and schematic illustrations, of Simmons Hall. A possible retrospective illustration, emerging from the application of the porosity operations appears in Figure 17.
A comparison among the early design descriptions and the actual Simmons Hall dormitory shows that some of the early conceptual schemes were partially or totally abandoned in the process of implementation. The building deviates from the descriptions of the design intent. For example, the building recesses generated by the rule schema A were partially reversed. And 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 structural or other requirements. For the same reason, the abstract concept of recursion was dropped rather early, and the intended window variety on the facades, was restricted to a single standard window, with the exception of a limited number of larger openings. Further, the indented creation of multiple cavities, via rule schema ∆ (vertical porosity) was hindered: only three vertical cavities were distributed to the overall building mass. Last, 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 of vertical circulation. A summarizing visual comparison among the early descriptions of intents and the finally implemented building configurations is presented in Table 8.

However, it is still accurate to say that the implementation of Simmons Hall falls within the design space that was determined by the concept of porosity. The final design can still be produced by instances of the parametric rule schemata A, Γ, ∆. The rule schema A introduces “pores” at a larger scale: that of the building mass. The rule schema Γ introduces “pores” at a smaller scale: that of the façade panel. And, the rule schema ∆ introduces organic cavities affecting both scales: the building’s mass and the interior space. The productive contribution of the “permeability” hypothesis and of the “porosity” concept was to focus the designers’ attention on
particular features of the problem, and to provide a basis for the building of a problem space containing these features. Making novel associations and building a non-trivial problem representation is essential in the production of novel solutions. It signifies what Holl describes as “remaining experimental and open”. Rather than simply solving a given program, within predetermined confines, what the architect contributes to is the exploration of new hypotheses. Then, the actual process of “making” supports or invalidates the hypothetical constructions. Holl [17] concludes: “By making, we realize that the idea is only a seed for extension in phenomena. Experience becomes a kind of reasoning distinct to the making of architecture. Whether reflecting on the unity of concept and experience or the intertwining of idea and phenomena, the hope is to unite intellect and feeling, precision with soul”.

5. CONCLUSION

For many architects and designers, the ability to diagnose problems and to formulate productive hypotheses plays a key role in the development of innovative design solutions in the studio. Productive hypotheses allow designers to interpret the available design information in new ways. They lead to the reframing of the problems and to the development of new methods of production. Productive hypotheses are associated with the introduction of concepts. The role of concepts in design is both descriptive and productive. Verbal descriptions, keywords and conceptual schemes set forth at the early stages of the design process are economical and inclusive means to frame a general approach.

Background assumption and motivation of this study is that a design concept is at its root a course of action meant to be performed by the designers in the studio. Design concepts are introduced contextually and jointly with a course of productive action that is organized and explained in terms of them. Interpreting the output of the action confers meaning on the concepts. This allows design concepts to evolve in parallel to designs. Design concepts become explicit as designers adapt their general schemes to specific contexts. This progression is analogous to moving from implicit principles to explicit modes of action and their parameters. From a computational standpoint this is analogous to moving from rule schemata to rules.

Novel aspect of this paper was to show how computational rules can be useful in describing the early productive design processes and their suppositions. It has presented a paradigm of how a design concept can be treated by formal-generative means in designing from scratch. And it has shown that a design concept can be converted into a system of visual rule schemata to generate design descriptions. The rule schemata were expressed by the means of shape grammar formalism. The paradigm was a retrospective analysis of how the concept of “porosity” was used by architect Holl and his team in designing the 350-unit student residence.
Simmons Hall, at MIT.

It was also pointed out that design concepts do not necessarily emerge out of the existing design representations, alone. But, they can be imports from domains foreign to design like biology, physics, mathematics, music, etc., which are transposed to design contexts, with a view to focus the designers’ attention on particular features of a problem and to propagate a certain course of productive action. Of course, the use of a word like “porosity” within a design context, does not guarantee the existence of a straightforward, formal way to identify the actions or the things it denotes, or to determine their features. However, the presented paradigm demonstrated that when there is a recurring structure, or a “characteristic pattern”, a domain can be specified for which rules and meanings can be resolved.

Computational rule schemata were found ideal for the framing of design concepts. It was proposed that there is no more to framing a design concept than there is to setting a number of grammatical rules. Setting rules is equal to identifying particular kinds of activity, usually of repetitive character. It requires dealing with relations and features. Being unable to make relational judgments prevents one from understanding how something can be “part of” something else and makes the grasping of a rule, or a concept, impossible. In applying a rule of the form $x \rightarrow y$, “awareness” of what stands as a complete $x$, and “judgment” to distinguish the appropriate place and time to make $x$ “part of” a description, are required. A characteristic pattern $x$, singled out by name, has the privilege to expand the domain of the matching places, as it prompts the viewer to discover incomplete $x$s. It provides the best basis for distinguishing places having the feature to be parts of $x$. Accordingly, a rule schema provides better means for treating an $x$-like-family of forms, than a rule that treats only a specific $x$-instance.

In conclusion, the early exploratory stages of design can benefit by a formal-generative methodology in multiple ways. The description of design concepts by rule schemata allows communicating abstract ideas with precision without sacrificing generality. And the mapping of the actions implied by a concept to computational rules, allows the implementation of design tools with strong generative capacity. The organization of sequences of rules leads to the construction of grammars. And, the rule sequences can be transferred to a programming language, as scripts, to become available for execution by digital machines. The encoding of design concepts into rules and custom computational tools makes the design process transparent and permits the future access and reuse of the design ideas.

In extension to the above, one may say that showing attention to the early conceptual design schemes may provide a link between intuitive and computational design methodologies. This is important in architectural design, where the distinction between general problem solving methods and
case-specific techniques is not firmly established. The development of custom
digital design tools without an outline of formal or spatial expectations often
absorbs a lot of designers’ energy and attention and drives them away from
their intended spatial objectives. The ability to retain associations with early
conceptual schemes assists in framing ideas of explicit patterns of activity and
assures that one is not dealing with irrelevant issues.

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