A Figurative Study of Louis Kahn's Capitol Complex at Dhaka: Analysis through Shape and Shape Grammars Theory

ルイスカーンのダッカ国際議事堂複合体に関する図形的な研究：形態・形態文法理論による分析

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In loving memory of my motherland, whom I miss so much.

"It seems very unaccountable that the generality of our late architects dwell so much upon [the] ornamental, and so slightly pass over the geometrical, which is the most essential part of architecture."

Sir Christopher Wren (1750)

Contents

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Preface:

Louis Kahn's architecture is driven by an urge to produce order, as intense as Le Corbusier's; although the path and the result are different. When dealing with Kahn it remains difficult to reconcile his idiosyncratic combination of faith in the metaphysics of a Platonically shaped truth with his fund of historical architectural models and the conflict-ridden synthesis of autonomy and functionality of form and their implementation within the reality of complex geometry. Considering the rational aspect of Kahn's architecture in this way leads to the essential insight that there is an all-embracing order in Kahn's work, and that is an order which can be understood: *order is*.

Kahn's Dhaka commission demonstrates his precise conception and extraordinarily decisive disposition to an idea that fascinated him; that of mastering a large volume. The project being handed in the early 60s took a rather slowed pace of progress to be finished only in the 80s. A posthumous glory of Kahn. *Concentricity* is a constant motif in Kahn's designs, from Trenton Bathhouse to Exeter Library. The composition of the prismatic volume, the flanking hostels, the axiality, etc. are too delicately maneuvered to produce an evident sense of ordering principle of historically motivated method of formalism blended into modern functionalism.

Comprehending the rational principles of the usage of formal geometry is one of the purposes of this investigation. Broadly speaking, 'contextualism' is the underlying theme of this research endeavor. A method, quantifiable and comparable, to establish a relationship between a design and its context is going to be the ultimate goal of this research. As a master thesis, this paper will only deal with the formulation of a method of analysis, synthesis and translation of a design work, Kahn's Capitol building, through the application of *shape and shape grammar (Stiny and Mitchell, 1978)* analysis.

Introduction to the Study

An architectural language, whether it belongs to a certain period or to an architect, has some compositional principles. These principles can be defined by a set of rules, which form the grammar of the language. The study presented in this thesis comprises the union of two basic themes:

- Deriving a shape grammar from a corpus of design (viz., Louis I Kahn's Capitol Complex being chosen in this very research).
- Generating languages for application in further designs ('contextualism' triumphing over 'globalization').

Shape and shape grammars, since its inception in late 70s by George Stiny and James Gips, had been used as a tool for analytical purposes to compute inherent design formula, in terms of shape and formal aspects, and make an understanding of the past designs. Now, the vision and process of using shape and shape grammars have emerged from its long abiding shell and come forward to be a tool not only for design analysis, but as a prognostic method to help designers sort principles and ideas to incorporate into new design ordeals. This study is a first step towards the formulation of a methodology towards using original design principles, viz. shape grammar and shape language, as a tool to use as guidelines for newer designs.

This thesis has been divided into three chapters. The first chapter is a detailed approach to understanding shape and shape grammar theory. It includes the history of development along with a detailed elaboration of the theory as conceived from different resources. This chapter is essentially helpful for the readers to completely comprehend the elements in chapter three.

The second chapter deals with the inauguration of the selected research premise. It includes historical reference for the selection of the project and briefs on the developmental phases. It exemplifies the planar elements in computer-generated drawings and simplifies the formal structure.

The third chapter is an account of the parametric shape grammar study of the selected plan elements. A detailed understanding would require recalling theories given in chapter one. The methodology is given in detail in this chapter.

Background of the Study

Shape grammars generate languages of architectural design (Cagdas, 1996). Rule-based formalism that encodes syntactical knowledge of architectural designs has been studied in many research projects about shape and shape grammars. These grammars are derived from a given corpus of designs of a particular style or tradition, for example, traditional Chinese lattice designs (Stiny, 1977), Palladian villa plans (Stiny and Mitchell, 1978), Mughul gardens (Stiny and Mitchell, 1980), Hepplewhite chair-back designs (Knight, 1980), Japanese tearoom plans (Knight, 1981), the architecture of Guisseppe Terragni (Flemming, 1981), bungalows of Buffalo (Downing and Flemming, 1981), the prairie houses of Frank Lloyd Wright (Koning and Eizenberg, 1981), Greek vase motifs (Knight, 1986), Queen Anne houses (Flemming, 1987), Ndebele homesteads (Herbert et al, 1994), and row-houses (Cagdas, 1996). The common point in all these studies is to regenerate the patterns of the products that belong to various languages of designs in a generative approach. These languages emerged as examples of vernacular architecture, neoclassical architecture, traditional garden designs, furniture designs and individual designs of some well-known architects.

Generation processes can be modeled on the transformations of shapes. Shape grammars are applications in which shapes are represented as design descriptions and transformed according to a rule-based formalism stated by Stiny (1980). Apart from the analytical approach of designs through shape grammar analysis, researches on the development of computational methods to formalize a methodology of design parameters to help designers in the process of design, rather than a tool for experimenting, are in progress too. Miranda Clare McGill, a master student from MIT has created software 'Shaper2D', facilitating the learning of shape grammars. Another doctoral student from the same school, Jose P Duarte is working on Alvaro Siza's Malagueira houses in order to devise a mechanism based on shape grammar principles that would help use Siza's design systems into newer designs. He states,

> … .. is an attempt to overcome such limitations and it is based on three arguments: (1) shape grammars can provide the technical apparatus to make Siza's design rules at Malagueira explicit; …… (3) shape grammars and computer programs, coupled with rapid prototyping and virtual reality techniques, can provide a digital framework for customizing the design of mass housing.

The aim of this study is rather precise. At this eon of globalization and internationalization, the thought of 'contextualism' in architecture can invite a chorus of contradictions in many aspects. However, as far as I am concerned, with the concept of 'architecture is a frozen culture' in mind, I strongly defend the theory of *contextualism*. I believe that understanding the innate shape grammar language of a particular setting through shape and shape grammar principles, the newer designs can absorb guidelines and principles to abide by the architectural texture of the setting or context. Shape language is certainly not the only parameter to rule out 'anachronosity' of a design in a setting, nevertheless, is a prime factor of the process.

The Problem Statement

'Can algorithm(s) be developed to help new designs?'

An evident question and this research do not bear the defense for such an elaborate issue. However, it does give insight on the possibility of such phenomenon. Louis Kahn's Capitol Complex at Dhaka is chosen as an arbitrary example for the execution of this study. The first question statement for this study was, whether a shape grammar language can be developed from a given corpus of design or not. It is possible to do one. These examples do date back to as early as the 80s. The second question is, whether this language help designers in a prognostic way. Can the designers take incentives or parameters from the language to give input into newer designs or not? In light of this question, this study is the first step towards achieving this goal. But, I believe that a language developed from a corpus of design can emerge as a tool. A tool to analyze the efficiency of the design work in terms of 'contextuality'. Since architecture is not purely a mathematical science and partly aesthetic subjectivity is incorporated, it is often difficult to analyze a work through figurative parameters. But, methods are developed. Software was developed to quantify and analyze the space syntax. This line of study can be used to bring out such possibility of formulation of a theory to develop a standard method of comparative tool. This is an exercise of the preliminary question, which is evidently the foundation for the work of the following broad research.

Nature of Study:

The 'architectural linguistics' is itself divided into two parts. There is that part which deals with *syntax* of possible architectural forms and arrangements. And there is that part which deals with the *semantics,* the system of meaning, which the syntactic forms and structures come to support. (Steadman, 1983) This study is confined entirely to the subject of architectural syntax.

The academic study of architecture can be seen as being divisible into three areas or disciplines. There is the professional training of designers in architectural schools. The analogy here is with learning to speak a language. There is the study of architectural history, from a critical and aesthetic point of view. This must correspond to the study of literary history and literary criticism. And, third, there is what I would suggest is the architectural counterpart to the discipline of linguistics: that is, an architectural science, devoted to a general investigations of the cultural and technological systems within which all architects work, and all buildings are produced. (Steadman, 1983.) This study belongs to the latter part.

It is popularly assumed that any architectural research of a mathematical nature must have functionalist aims and it seeks to devise ways in which the design of a building can be formulated as a mathematical 'problem' and mathematically 'solved'. This study aims to provide light on an area of research which, though mathematical in nature, and although computers are certainly used, has quite different aims and is based on a very different conception of the nature of architectural design. Analyzing through shape and shape grammar theory (Stiny, 1980) can help formulate a language of a design work. This process is often a resultant of some shape rules or schema, which are created based on the original design. These rules and/ or schema, along with the shape grammar algorithm would constitute part of the broad intellectual makeup of the designer, part of the mental apparatus that one brings to bear in design.

Overview of Methodology:

The use of shape and shape grammar formalism provides for a series of methodologies. The methodology applied here refers to the method introduced by George Stiny and William J Mitchell in their paper "The Palladian Grammar", published in the *Environment and Planning B* (volume 5) in 1978. The basic theories abides by the shape and shape grammar definitions incorporated by Stiny (1975), (1980), and Gips (1975). The shapes, chosen from the master plan of Louis I Kahn's Capitol Complex at Dhaka, were analyzed in reference to the papers by G. Stiny's "The Palladian grammar" from *Environment and Planning B* 5, 1978; U. Flemming's "The secret of the Casa Guiliani Frigerio" from *Environment and Planning B* 8,1981, and T W Knight's "The forty-one steps" from

Environment and Planning B 8, 1981. The rules of analysis pertain to the 'parametric shape grammar' analysis.

The geometry of Kahn's Capitol plan is studied instead of other aspects of his architectural system, for example, the use of different fenestration, because it characterizes the Kahn style in a fundamental sense.

Shapes are realized in Cartesian system of coordinates. Instead of shape rules, a parametric *shape rule schemata,* or *schemata* for short; from any such schema a specific shape rule can be derived through an assignment of values, *g*, to the parameters in the schema.

Delimitations of Study:

When several buildings each create a similar impression, they are said to exemplify a particular architectural *style.* Given a finite corpus of buildings that are perceived to be alike in some sense, the problem of style consists of characterizing the basis for this likeness. Ideally this characterization has three main purposes:

(1) It should clarify the underlying commonality of structure and appearance manifest for the buildings in the corpus;
(2) It should supply the conventions and criteria necessary to determine whether any other building not in the original corpus is an instance of the style; and
(3) It should provide the compositional machinery needed to design new buildings that are instances of the style.

If the characterization of a particular architectural style is to have any explanatory or predictive value, it must satisfy these descriptive, analytic, and synthetic tests of adequacy. (Stiny and Mitchell, 1978)

The parametric shape grammar given for the generation of Louis Kahn's

Capitol building office plans may be considered a partial definition of the Kahn's style. A more complete definition would require a grammar for facade generation and more detailed treatment of Kahn's system of proportion. Clearly, this generative characterization satisfies the preceding criteria: the rules of the grammar elucidate the structure and appearance of public building plans designed by Kahn's approach; any office plan, to be designed newly at the same site, can be generated by the grammar. However, it should be noted that the grammar given here is arbitrary in certain respects. The corpus of buildings to be described might have been selected in a different way. I might have restricted it to Kahn's Capitol building only, or I might have attempted to broaden it to include all of the designs in the project. A change in definition of the corpus might result in changes in the grammar.

Furthermore the definition of what constitutes a trivial or accidental variation in form, which need not be accounted for by the grammar, is also arbitrary to some extent. I have simply exercised my best judgment on these matters. Different decisions would not affect the grammar in any fundamental way.

The definition of the Kahn's style of buildings in Dhaka by use of the parametric shape grammar specified here allows other issues and questions of aesthetic and historical interest to be investigated. For example, the grammar provides the basis for classifying public building designs in terms of the properties of the sequences of rules applied to generate their plans of a certain type. Indeed a simple combinatorial analysis of possible sequences of rule applications would allow for the computation of the number of all possible buildings that have an underlying pattern of grammar.

Finally, by use of this aesthetic system, a detailed critical account of building plans could be given in terms of algorithmically based interpretive conventions and evaluative criteria corresponding to Kahn's own.

CHAPTER ONE ½ LEARNING ABOUT SHAPE AND SHAPE GRAMMARS

"… One must know and understand the alphabet before words can be formed and a vocabulary developed; one must understand the rules of grammar and syntax before sentences can be constructed; one must understand the principles of composition before essays, novels, and the like can be written. Once these elements are understood, one can write poignantly or with force, call for peace or insight to riot, comment on trivia or speak with insight and meaning."

(Ching, 1979, p.11)

A Brief History of Development

Introduction:

George Stiny and James Gips invented shape grammars over twenty-five years ago. They were one of the earliest algorithmic systems for creating and understanding designs directly through computations with shapes, rather than indirectly through computations with text or symbols. Over the years, shape grammars have been explored through applications addressing a variety of design problems. Shortly after their invention, Stiny outlined a two-part project for shape grammars. In a 1976 paper in *Environment and Planning B* 3:(187-210), "Two exercises in formal composition", Stiny described two exercises in formal composition. These simple exercises became the foundation for the many applications of shape grammars that followed, and suggested the potential of such applications in education and practice. The first exercise showed how shape grammars could be used in original composition, that is, the creation of new design languages or styles from scratch. The second exercise showed how shape grammars could be used to analyze known or existing design languages. Both exercises illustrated the unique characteristics of the shape grammar formalism that helped motivate a quarter century of shape grammar work. General but simple, formal yet intuitive: qualities that continue to make shape grammar disciples and confound skeptics.

HISTORY OF APPLICATIONS IN ARCHITECTURE

Original design:

Interestingly, the earliest applications of shape grammars were in an area and for a purpose quickly dropped and not taken up again for a number of years. The first published paper on shape grammars by Stiny and Gips in

1972, illustrates shape grammars for original languages of paintings. The published theses of Gips and Stiny both from 1975, and the joint Stiny and Gips book *Algorithmic Aesthetics* from 1978, also illustrate the shape grammar formalism with original grammars for paintings. The shape grammars in these works are embedded in aesthetic systems for interpreting and evaluating works of art.

Stiny and Gips do not explore or explain the genesis of the original grammars they give in their early works. A specific approach for creating original grammars from scratch was first proposed in 1980 by Stiny in his paper, "Kindergarten grammars: designing with Froebel's building gifts"5. Stiny examines the kindergarten method of Frederick Froebel and its analogy in the studio method of designing, and then proposes a constructive alternative to these mostly intuitive methods. A five-stage program is given for creating new design languages: a vocabulary of shapes, spatial relations, shape rules, initial shape, and shape grammars. Stiny uses Froebel's building blocks in the many simple and elegant shape grammars and designs created with this approach. These shape grammars are the first defined in a three-dimensional space, laying the groundwork for three-dimensional architectural grammars to come. Stiny's kindergarten program for creating original grammars lay dormant for several years while analytic applications of shape grammars grew quickly.

Analysis:

The first two decades of shape grammar applications focused almost exclusively on analysis. Through this work, shape grammars became an established paradigm in design theory, CAD, and related fields. The first analytic exercise with shape grammars was given by Stiny in his paper, "Ice-

ray: a note on the generation of Chinese lattice designs" (Stiny, 1977). The grammar laid out in this paper sets the standards for shape grammars that followed. With five simple rules, the grammar captures the compositional conventions of lattice designs, generates existing lattice designs and an infinite number of new, hypothetical designs in the same style.
The second analytic application of shape grammars, the Palladian grammar by Stiny and Mitchell from 1978, initiated work on more ambitious and complex shape grammars for architectural styles that continues today. The Wright grammar is notable for being the first three-dimensional architectural grammar--motivated in part by Stiny's earlier work on kindergarten grammars and the alleged influence of Froebel on Wright's architecture.

Analysis/original design:

In practice, original languages are not created from scratch, but from past or existing ones. This approach to original design lies behind work combining analytic and synthetic approaches. In 1981, Knight proposed a method for developing new languages of designs on the basis of existing ones. Languages are created by transforming the spatial relations underlying grammars for existing languages. In other words, a known style is first analyzed by inferring a grammar for it, the rules of the grammar are transformed, and then the transformed rules become the basis for a new grammar and style. Knight's model had a dual purpose. It could be used to characterize the historical evolution of known styles into succeeding ones. It could also be used to innovate new styles on the basis of given ones.

Current, very promising work by three doctoral students in the Design and Computation program at MIT is in the same spirit. Each student is working on a shape grammar for an existing style of architecture. Unlike earlier analytic grammars, these grammars are being developed with very specific practical or pedagogical goals in mind. They are not just meant to be "read". They are meant to be used. Each grammar will have some degree of flexibility built in so that potential users of the grammar will not only be able to understand and generate designs in the original style, they will be able to generate new designs in a broadening of the style. To achieve these goals, the grammars will incorporate new grammatical or other devices such as description grammars, parallel grammars, color grammars, or multiple algebras. The grammar is being structured in such a way that it can be used by students to generate and explore variations of the system.

INTRODUCTION TO SHAPE AND SHAPE GRAMMARS:

Shape Definition:

A shape *is a limited arrangement of straight lines defined in a Cartesian coordinate system with real axes and an associated euclidean metric.*

In order to formalize this idea, the following definitions pertaining to lines are used:

A *line* l, $l = \{p_1, p_2\}$, is determined by any set of two distinct points p_1 and p_2, called the *end points* of the line. A line always has limited but nonzero length. Two lines are equal if and only if they have the same end points. A point p is *coincident* with a line l having end points p_1 and p_2 if and only if p is an end point of l or the length of l is equal to the sum of the lengths of the two lines l', $l'' = \{p_1, p\}$, and l'', $l'' = \{p, p_2\}$, having end points p_1 and p, and p and P_2, respectively. Two lines l_1 and l_2 are *collinear* if and only if the end points of l_1 and l_2 are all coincident with a line determined by two of these end points. Notice that colinearity is an *equivalence* relation for lines.

Every shape is specified by a finite set of lines, no two of which can be combined to form a single line. Two unequal lines combine to produce one whenever

(1) the two lines share an end point and the remaining end point of one line is coincident with the other line;

(2) both end points of one line are coincident with the other line;

(3) one end point of each line is coincident with the other line; or

(4) the two lines share an end point and this point is coincident with the line formed by the two remaining unshared end points.

In these four cases, the two lines are collinear. The elements in the set of lines specifying a shape are called *maximal lines,* as they are not parts of longer lines in the shape. The shape specified by a set of maximal lines can be represented graphically by drawing the lines in the set. The shape specified by the set containing no maximal is called the *empty shape,* and is denoted by $s_{\emptyset}$. Intuitively, the empty shape is a blank space.

Subshape and identity relations for shapes:

One shape is a subshape (part) of another shape whenever every line of the first shape is also a line of the second shape. More precisely, a line is *in* a shape if and only if its end points are coincident with a maximal line of the shape. Thus, a shape s_1 is a *subshape* of a shape s_2 (denoted by s_1£s_2) if and only if each maximal line of s_1 is in s_2. Thereby, the empty shape is a subshape of every shape.

It is easy to see that every shape but the empty shape has an unlimited number of distinct subshapes. Take any maximal line of a shape *s.* Any two distinct points coincident with this line form a new line that is a subshape of *s.* There are an unlimited number of distinct pairs of such points and, hence, an unlimited number of distinct subshapes of *s.* Further, any finite combination of such lines defined in possibly different maximal lines of s is also a subshape of s.

Two shapes are identical whenever they have the same lines. More precisely, the shapes s_1 and s_2 are *identical* (denoted by $s_1 = s_2$) if and only if each is a subshape of the other. In this case, the sets of maximal lines specifying the shapes are equal.

When the shape identity relation defines shape equality, the subshape relation is a *partial order* on sets of shapes. The set of all subshapes of a given shape and the subshape relation determine a *lattice.* This particular lattice is infinite in extent; it is a complete representation of the interrelations between all of the possible component elements of the shape. A finite lattice is determined by the set of shapes containing the empty shape, the maximal lines for a given shape, and all of the shapes specified by some combination of these lines, together with the subshape relation.

Boolean operations for shapes:

The shape union of shapes s_1 and s_2 (denoted by $s_1 + s_2$) is the shape consisting of all of the lines in s_1 or s_2 or produced by combining lines in s_1 or s_2. A maximal line of s_1 and a maximal line of s_2 can combine to form a new, longer maximal line in their shape union. Thus, there may be lines in this shape that are in neither s_1 nor s_2. The shapes s_1 and s_2 are both subshapes of the shape $s_1 + s_2$.

The *shape intersection* of shapes s_1 and s_2 (denoted by $s_1 \bullet s_2$) *is* the shape consisting of just those lines in both s_1 and s_2. The shape $s_1 \bullet s_2$ is a subshape of the shape s_1 and a subshape of the shape s_2. The *shape difference of* shapes s_1 and s_2 (denoted by $s_1 - s_2$) is the shape consisting of just those lines in s_1 that are not also lines in s_2. The shape $s_1 - s_2$ is always a subshape of the shape s_1 but need not be a subshape of the shape s_2.

The operations of shape union, intersection, and difference treat shapes in the same basic way as the set-theoretic operations of union, intersection, and difference treat sets. More precisely, the set of all subshapes of a given shape *s* and the operations of shape union and intersection form a *Boolean algebra.* That is, shape union and intersection are both closed on this set. These operations are commutative, and each is distributive relative to the other. The empty shape is the identity element for shape union; the shape s is the identity element for shape intersection. The complement t^{-} for any shape t in the set is given by the shape difference of *s* and *t*, that is, $t^{-}=s-t$. As t^{-} is a subshape of *s*, it is also in the set. It is also noticeable that the finite set of shapes containing the empty shape, the maximal lines for a given shape *s,* and all of the shapes specified by some combination of these lines, together with the operations of shape union and intersection also forms a Boolean algebra.

Transformations of shapes:

The euclidean transformations provide for new shapes to be produced by changing the location, orientation, reflection, or size of a given shape. These *transformations* are *translation, rotation, reflection, scale,* or finite *compositions* of them. A transformation that does not involve scale is called an *isometry.*

A transformation $\hat{o}$ of a shape *s* is the shape denoted by $\hat{o}(s)$. Any transformation of the empty shape is the empty shape. Two shapes are geometrically similar when one can be changed into the other by a transformation. More precisely, a shape s_1 is *similar* to a shape s_2 if and only if there is a transformation $\hat{o}$ such that $\hat{o}(s_1)$ is identical to s_2. The shapes s_1 and s_2 are *congruent* if and only if the transformation $\hat{o}$ is an isometry.

The sets of shapes S^+ and S^*:

A finite set of shapes may be used as the vocabulary for the formation of other shapes. It is said that a shape is *made up* of elements in a given set of shapes whenever it is the shape union of transformations of shapes in this set.

The set of all shapes made up of shapes in a given set of shapes S is denoted by S^+. In mathematical terminology, the set S^+ is the least set containing all of the shapes in the set S that is closed under shape union and the transformations. For example, if the set S contains only one shape consisting of a single straight line, then the set S^+ contains all possible shapes made up of one or more maximal lines. Any such shape is just the shape union of its maximal lines, which are transformations of the shape (line) in the set S, and, hence, is an element in the set S^+. For a given set of shapes S, the set of shapes S^* contains in addition to all of the shapes in the set S^* the empty shape $s_Ø$.

Labeled shapes:

Aspects of a shape can be distinguished by labeling it. The following simple definitions are needed for this purpose.

A *labeled point* $p{:}A$ is a point p with a symbol A associated with it. Two labeled points $p_1{:}A_1$ and $p_2{:}A_2$, are the same if and only if the points p_1 and p_2 and the symbols A_1 and A_2 are the same. A transformation $\hat{o}$ of a labeled point $p{:}A$ is the labeled point $\hat{o}(p){:}A$, where $\hat{o}(p)$ is the point produced by applying $\hat{o}$ to p. The symbol associated with a labeled point is invariant under the transformations. A transformation $\hat{o}$ of a set of labeled points P is the set of labeled points $\hat{o}(P)$ produced by applying the transformation $\hat{o}$ to each labeled point in P.

A labeled shape consists of two parts: a shape and a set of labeled points. More precisely, a *labeled shape* ó is given by an ordered pair ó = (s, P), where *s* is a shape and *P* is a finite set of labeled points. The labeled points in the set *P* are located with respect to the shape *s.* These labeled points may be coincident with the lines in *s,* but this need not be the case. A labeled shape ó can be represented graphically by drawing the shape *s,* and indicating the occurrences of the labeled points in the set *P.*

The labeled shape consisting of a shape *s* but with no symbols associated with it is denoted by *(s,* Ø), where Ø is the set of labeled points containing no elements. Symbols may be associated with the empty shape $S_Ø$ to produce a labeled shape ($S_Ø$, P), where *P* is a nonempty set of labeled points. The *empty labeled shape* is given by ($S_Ø$, Ø)) and corresponds to a blank space. Relations and operations on shapes can be extended to labeled shapes:

For labeled shapes ó$_1$ and ó$_2$ given by ó$_1$ = (s_1, P_1) and ó$_2$ = (s_1, P_1), ó$_1$ is a *subshape* of ó$_2$, (denoted by ó$_1$ ó$_2$) if and only if the shape s_1 is a subshape of the shape s_2 and the set P_1 is a subset of the set P_2. The two labeled shapes ó$_1$ and ó$_2$ are *identical* (denoted by ó$_1$ = ó$_2$) if and only if each is a subshape of the other.

The *shape union* of ó$_1$ and ó$_2$ (denoted by ó$_1$ + ó$_2$) is the labeled shape consisting of the shape union of s_1 and s_2 and the union of the sets P_1 and P_2. That is, ó$_1$ + ó$_2$ = ($s_1 + s_2$, $P_1 + P_2$).

The *shape intersection* of ó$_1$ and ó$_2$ (denoted by ó$_1$ • ó$_2$) is the labeled shape *consisting* of the shape intersection of s_1 and s_2, and the intersection of the sets P_1 and P_2. That is, ó$_1$ • ó$_2$ = ($s_1 \bullet s_2$, $P_1 \bullet P_2$).

The *shape difference* of ó$_1$ and ó$_2$ (denoted by ó$_1$ — ó$_2$) is the labeled shape consisting of the shape difference *of* s_1 and s_2, and the difference of the sets P_1 and P_2. That is, ó$_1$ — ó$_2$= ($s_1 — s_2$, $P_1 — P_2$).

A transformation *ô* of a labeled shape ó, ó = (*s,P),* is the labeled shape *ô*(ó) given by { *ô(s*), *ô(P)}.* Two labeled shapes are *similar* if there is a transformation that makes one identical to the other. If the transformation is an isometry, then the labeled shapes are *congruent.*

Families of shapes:

So far, we have considered only individual shapes. A family of shapes can be defined in terms of a given shape by allowing its component elements to be dimensioned in accordance with certain specified criteria.

More precisely, *a family* of shapes is defined by a *parameterized shape s,* which is obtained by allowing the coordinates of the end points of the maximal lines in a given shape to be variables. A particular member of this family is determined by an *assignment g of* real values to these variables. These values may be required to satisfy certain specified conditions. The result of applying the assignment *g* to the parameterized shape *s* is the shape denoted by *g(s).*

Parameterized shapes and their assignments may be considered as generalizations of transformations applied to shapes. In addition to allowing the locations, orientations, reflections, and sizes of shapes to be changed, parameterized shapes provide for shapes to be distorted in certain ways. Assignments to parameterized shapes can, in general, vary any spatial aspect of a shape, for example, angles and intersections of lines and the ratios between lengths of lines, so long as lines remain straight.

Families of labeled shapes can be defined by parameterized labeled shapes. A *parameterized labeled shape* ó is given by ó = *(s, P),* where *s* is a parameterized shape, and *P* is a finite set of labeled parameterized points. A *labeled parameterized point p:A* is a labeled point where the coordinates of *p* are variables. A member of the family of labeled shapes defined by *ó* is determined by an assignment *g* of real values to all of the variables associated with end points of maximal lines in *s* or elements in *P*. These values may be required to satisfy certain specified conditions. The labeled shape produced by applying *g* to ó *is* given by *g(*ó*)* = {*g(s), g(P)*}.

The shape grammar formalism:

The shape grammar formalism allows for algorithms to be defined directly in terms of labeled shapes and parameterized labeled shapes. Each such algorithm defines a language of shapes.

Shape grammars

A *shape grammar* has four components:

(1) *S* is a finite set of shapes;

(2) *L* is a finite set of symbols;

(3) R is a finite set of *shape rules* of the form *á â,* where (*á* is a labeled shape in (*S, L*)$^+$, and *â* is a labeled shape in *(S, L*)*; and

(4) I is a labeled shape in *(S, L)*$^+$ called the *initial shape.*

In a shape grammar, the shapes in the set *S* and the symbols in the set *L* provide the building blocks for the definition of shape rules in the set *R* and the initial shape *I.* Labeled shapes generated using the shape grammar are also built up in terms of these primitive elements.

A shape rule consists of two labeled shapes, one on each side of the arrow. These labeled shapes and the initial shape *I* are made up of shapes in the set *S* and symbols in the set *L.* Neither the labeled shape on the left-hand side of a shape rule nor the initial shape are allowed to be the empty labeled shape ($s_Ø$,Ø), but the labeled shape on the right-hand side of a shape rule is so allowed. Shapes in shape rules and the initial shape are labeled to help guide the shape generation process.

A shape rule *á â* applies to a labeled shape γ when there is a transformation *ô* such that *ô*(*á*) is a subshape of γ, that is, *ô*(*á*)[γ*.* Unless stated otherwise, it is assumed that *ô* is a general transformation. In this case, *á* is similar to some part of γ. However, one reserves the right to restrict *ô* to special kinds of transformations. For example, one may require *ô* to be an isometry. In this case, *á is* congruent to some part of γ.

The labeled shape produced by applying the shape rule *á* *â* to the labeled shape γ under the transformation *ô* is given by [*γ*2*ô*(*á*)] + *ô*(*â*). This labeled shape is formed by *replacing* the occurrence of *ô*(*á*) in γ with *ô*(*â*). That is, one first takes the shape difference of γ and *ô*(*á*), and then takes the shape union of this labeled shape and *ô*(*â*). It is notable that the application of the shape rule has the effect of erasing the occurrence of *ô*(*á*) in γ whenever *â* is the empty labeled shape.

Labeled shapes are generated by a shape grammar by applying the shape rules one at a time to the initial shape or to labeled shapes produced by previous applications of shape rules. A given labeled shape γ is *generated* by the shape grammar if there is a finite series of labeled shapes beginning with the initial shape and ending with γ such that each term in the series but the first is produced by applying a shape rule to its immediate predecessor.

A shape grammar defines a set of shapes called a *language.* This language contains all of the shapes *s* generated by the shape grammar that have no symbols associated with them, that is, labeled shapes of the form *(s,* Ø). Each of these shapes is derived from the initial shape by applying the shape rules; each is made up of shapes or subshapes of shapes in the set *S.*

(Shape grammars can also be used to define languages of labeled shapes, for example, languages containing certain kinds of architectural plans or mathematical diagrams. In this case, the definition of a shape grammar is extended to have two disjoint sets of symbols L_1 and L_1. Symbols in L_1 are nonterminal or auxiliary ones; symbols in L_1 are terminal ones. Shape rules are defined in terms of the symbols in the set L_1+L_2. Labeled shapes in the language defined by the shape grammar have only terminal symbols associated with them.)

The definition of shape grammars is made clear by a simple example. Consider the shape grammar of figure 1 which is specified by giving its shape rules and initial shape. In general, when no confusion can result, this simplified method of specification is used. The labeled shapes in the two shape rules and the initial shape are made up of a square and the symbol •.

The labeled shape on the left-hand side of both shape rules consists of a square and the symbol • located at the midpoint of one of its edges. The labeled shape on the right-hand side of the first shape rule consists of this square and another one inscribed in it. Each vertex of the inside square coincides with the midpoint of a different edge of the outside square. The symbol • is located at the midpoint of an edge of the inside square. The labeled shape on the right-hand side of the second shape rule consists of the square on its left-hand side.

The initial shape is a labeled square with the symbol • at the midpoint of one of its edges.

The generation of a shape using the shape grammar of figure 1 is shown in figure 2. The first shape rule is applied to the initial shape in step I and to the resulting labeled shape in step 2. This shape rule applies only to labeled shapes that contain a square with the symbol • associated with the midpoint of one of its edges. The shape rule inscribes a square, also labeled in this way, in the labeled square corresponding to its left-hand side and erases the symbol • associated with this square. As a result, the symbol • is always associated with the midpoint of an edge of the most recently inscribed square. Thus, the first shape rule can be applied to the initial

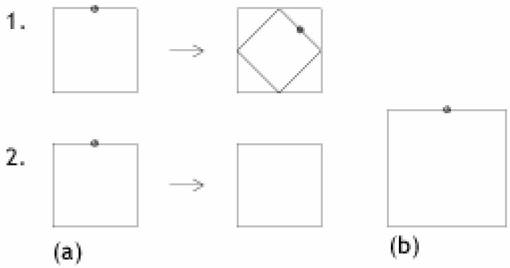


Figure 1. A simple shape grammar that inscribes squares in squares; (a) Shape rules, (b) initial shape.

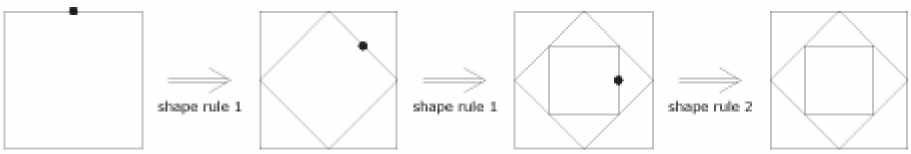


Figure 2. Generation of a shape using shape grammar of figure 1.

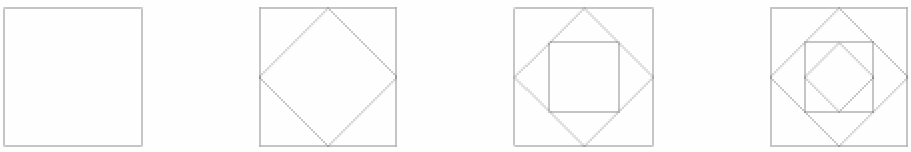


Figure 3. Some shapes in the language defined by the shape grammar of figure 1.

shape and to each labeled shape produced during the shape generation process at most one time. Because the labeled shape on the left-hand side of the first shape rule is a subshape of the labeled shape on its right-hand side, it can be applied again to any labeled shape already produced by applying it. The second shape rule is applied in step 3 of the generation. The left-hand side of this shape rule is identical to the left-hand side of the first shape rule, and hence it applies in identical circumstances. The second shape rule erases the symbol • associated with the midpoint of an edge of a square to produce a shape in the language defined by the shape grammar. The other steps in the generation do not contain shapes in this language, as the symbol • is associated with each of the shapes in these steps. No shape rule can be applied after the second shape rule has been used, because both shape rules require the occurrence of the symbol • to be applied.

The language defined by the shape grammar of figure 1 contains shapes consisting of *n* (/ 1) squares, one inscribed in another. Some of these shapes are shown in figure 3. It is to be noted that the bounding square for all such shapes is always the same.

Parametric shape grammars:

Parametric shape grammars are an extension of shape grammars in which shape rules are defined by filling in the open terms in a general schema. A shape rule *schema á* *â* consists of parameterized labeled shapes *á* and *â,* where no member of the family of labeled shapes specified by *á* is the empty labeled shape. Whenever specific values are given to all of the variables in *á* and *â* by an assignment *g* to determine specific labeled shapes, a new shape rule *g(á)* *g(â)* is defined. This shape rule can then be used to change a given labeled shape into a new one in the usual way. More precisely, if there is a transformation *ô* that makes *g(á)* a subshape of the given labeled shape, then this occurrence of the labeled shape *ô*[*g(á)*] can be *replaced* with the labeled shape $\hat{o}[g(\hat{a})]$. Unless explicitly restricted, $\hat{o}$ is a general transformation. It will be said that a shape rule schema applies to a labeled shape whenever it defines a shape rule that applies to the labeled shape.

The implications of these generalizations are illustrated in the following simple example. Considering the parametric shape grammar given in figure 4, which may be viewed as a generalization of the shape grammar defined in figure 1. Where the shape grammar generates shapes by inscribing squares in squares, the parametric shape grammar generates shapes by inscribing convex quadrilaterals in convex quadrilaterals.

The parametric shape grammar contains three shape rule schemata:
1. The first schema defines shape rules that replace a point labeled by the symbol ■ with a convex quadrilateral having one of its edges labeled by the symbol •. The left-hand side of the schema consists of a labeled parameterized point (x_1,y_1): ■; the right-hand side consists of a parameterized quadrilateral *q* with vertices at the points (x_1, y_1), (x_2, y_2), (x_3, y_3), and (x_4, y_4) and a labeled parameterized point (x_5, y_5): •.

Values assigned to the variables in the schema satisfy these conditions:
(a) The points (x_1, y_1), (x_2, y_2), (x_3, y_3), and (x_4, y_4) are the vertices of a convex quadrilateral.
(b) The point (x_5, y_5) is the midpoint of the line with end points (x_3, y_3) and (x_4, y_4).

2. The second schema defines shape rules that inscribe one convex quadrilateral in another one so that each of the vertices of the inside one is coincident with a different edge of the outside one. The left-hand side of the schema consists of the parameterized quadrilateral *q* and the labeled parameterized point (x_5, y_5): •; the right-hand side consists of the

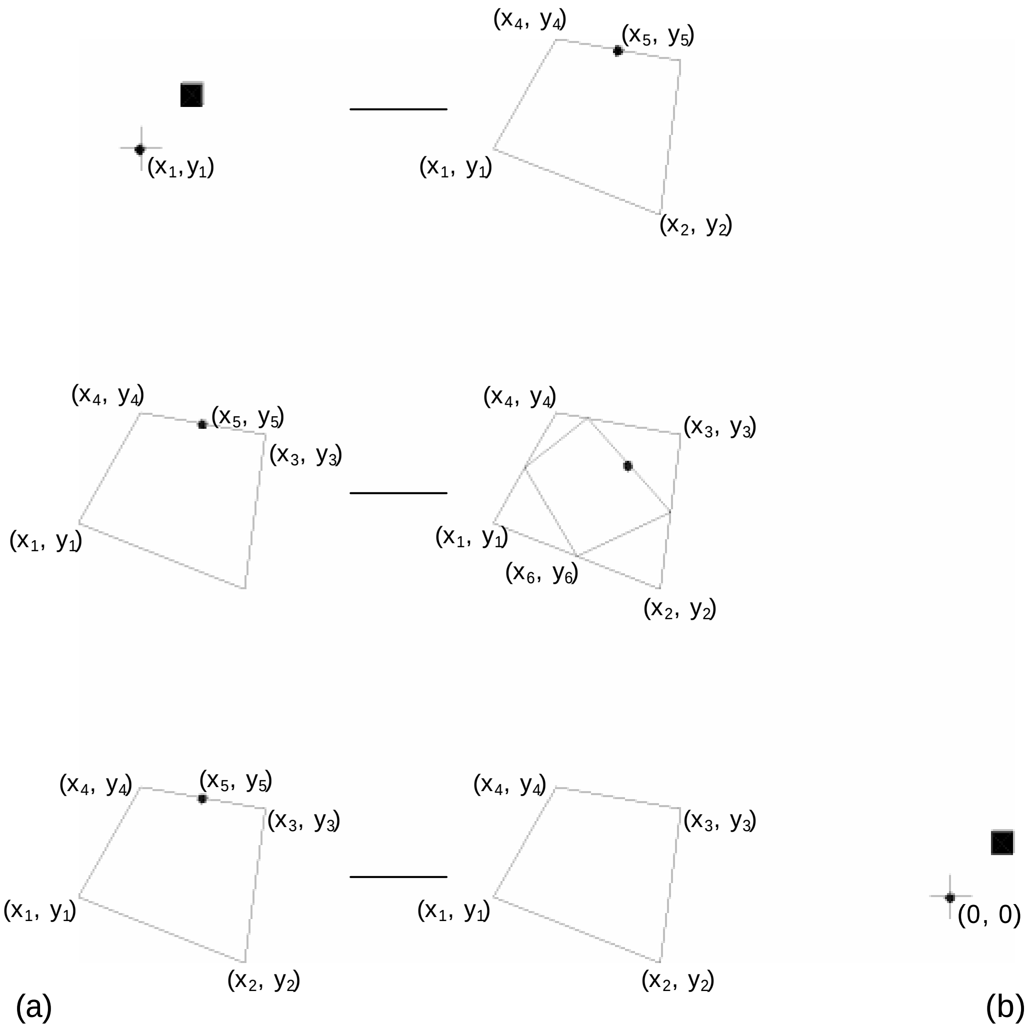


Figure 4. A simple parametric shape grammar that inscribes convex quadrilaterals in convex quadrilaterals. (a) Shape rule schemata, (b) initial shape.

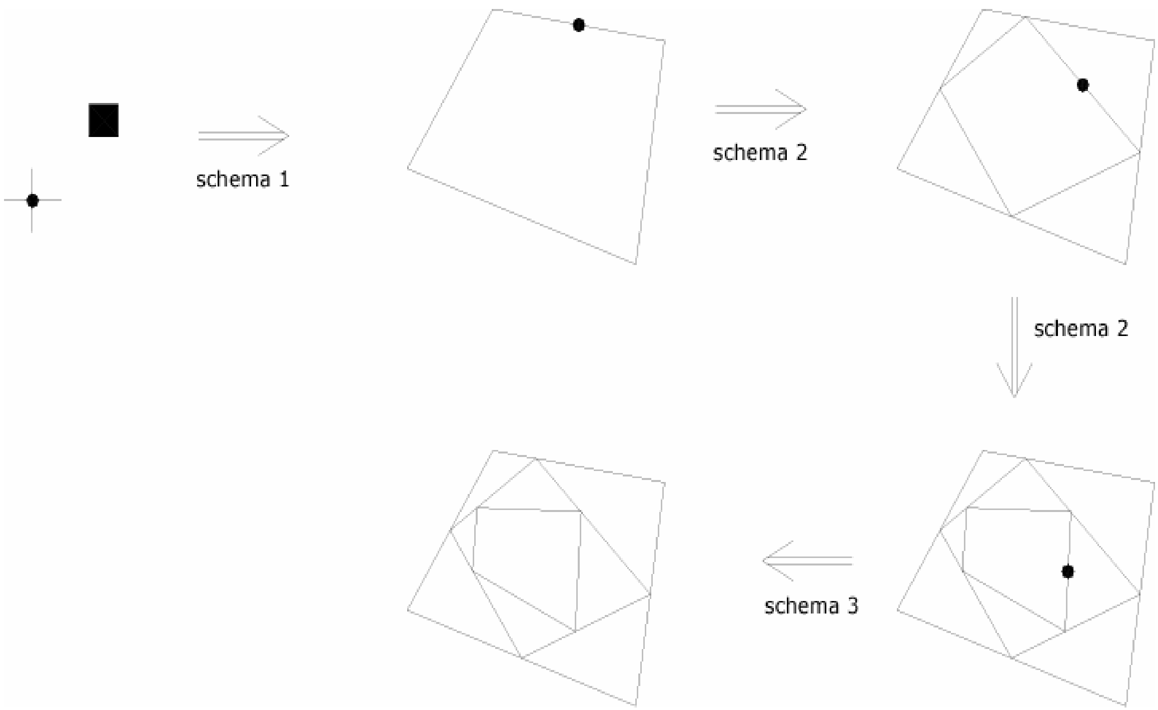


Figure 5. Generation of a shape using the shape grammar of figure 4.

parameterized quadrilateral *q,* another parameterized quadrilateral *r* with vertices at the points (x_6, y_6), (x_7, y_7), (x_8, y_8), and (x_9, y_9), and a labeled parameterized point (x_{10}, y_{10}): •. Values assigned to these new variables satisfy these conditions:

(c) The points (x_6, y_6), (x_7, y_7), (x_8, y_8), and (x_9, y_9), are coincident with the lines having end points (x_1, y_1) and (x_2, y_2), (x_2, y_2) and (x_3, y_3), (x_3, y_3) and (x_4, y_4), and (x_4, y_4) and (x_1, y_1) respectively, but are not these points.

(d) The point (x_{10}, y_{10}) is the midpoint of the line with end points (x_7, y_7) and (x_8, y_8). Conditions (a) and (c) guarantee that any two quadrilaterals determined by assigning values to the variables in *q* and *r* are both convex.

3. The third schema defines shape rules that erase the symbol • from the edge of a convex quadrilateral. The left-hand side of the schema consists of the parameterized quadrilateral *q* and the labeled parameterized point (x_5, y_5): •; the right-hand side consists of the parameterized quadrilateral *q.*

The initial shape of the parametric shape grammar consists of the labeled point (0, 0): ▪. It is to be noted that initial shape is a labeled shape and not a parameterized labeled shape.

The generation of a shape using the parametric shape grammar of figure 4 is shown in figure 5. The first schema is applied to the initial shape in step 1. The schema is used to define the shape rule shown beneath the step. This shape rule changes the initial shape into a labeled convex quadrilateral. The second schema is applied in steps 2 and 3 to the labeled shapes produced in steps 1 and 2. The schema is used to define the shape rules shown beneath steps 2 and 3. Each of these shape rules has a left-hand side that is similar to the quadrilateral with an edge marked by the symbol • in the labeled shape to which it is applied. The shape rule inscribes a new quadrilateral with an edge marked by the symbol • in the distinguished quadrilateral and erases the symbol • associated with it. It is to be noted that the recurrence of the symbol • in the schema prevents it from being used to inscribe more than one quadrilateral in any given quadrilateral. For any shape rule defined by the second schema, there are other shape rules, also defined by the schema, with left-hand sides similar to the labeled quadrilateral in the right-hand side of the original shape rule. Consequently, the second schema can be applied again to any labeled shape already produced by applying it. The third schema is applied in step 4 to the labeled shape produced in step 3. The schema is used to define the shape rule shown beneath the step. This shape rule terminates the shape generation process by erasing the symbol •.

The language defined by the parametric shape grammar of figure 4 contains shapes consisting of *n* (/1) convex quadrilaterals, one inscribed in another. The shapes generated in figure 5 are members of this language.

[Note: The above texts and materials, in part, are compiled and edited from Stiny (1975), (1980), Gips (1975) and Knight (2001, Internet edition). A few of the materials are directly reproduced from available published materials. The most comprehensive reference for shape grammar learning is probably the *Environment and Planning B* journal, published from UK by Pion Limited.]

CHAPTER TWO ½ THE CAPITOL PROJECT

"Lou Kahn materially influences every architect, not merely through his visible works of architecture, but by the principles he enunciated so beautifully…."

(Norman Rice)
(from the remarks made at memorials for Kahn
in Philadelphia and New York)

The Dhaka Capitol Commission

> "What I am trying to do is establish, out of philosophy, a *belief* that I can turn over to Pakistan, now Bangladesh, so that whatever they do is always answerable to it. I feel as though this plan, which was made weeks after I saw the program, has strength. Does it have all the ingredients? If only one is lacking, it will disintegrate."
>
> *(Louis Kahn in 'Perspecta' vol.9/10, 1965)*

Prologue:

The National Assembly complex in Dhaka, Bangladesh, is not often visited except by the most dedicated architectural enthusiasts. It remains among the least understood of Louis Kahn's major projects. Yet, along with the Salk Institute in La Jolla, which was designed in the same period, it constituted the first full realization of Kahn's mature architectural vision. The National Assembly complex was conceived when Dhaka was the capital city of East Pakistan. Many elements of its design — there were more than 10,000 drawings in all—were never built, and the complex was completed in 1983, nine years after he died. Still, even in what was executed, Kahn, having the good fortune of creative freedom and an ample budget, succeeded in weaving the various strands of his social and architectural agenda into a vital civic monument that is perhaps the crowning achievement of his career.

Kahn received the commission for the National Assembly complex in late 1962—the commission from Jonas Salk came that same year—and he designed it principally from 1963 to 1966, beginning just as the First Unitarian Church in Rochester was nearing completion. The National Assembly complex, housing a democratic parliament and associated functions, is the apotheosis of Kahn's long search for a new kind of modernism that transforms monumentality into a symbolic vehicle for the nurturing of a participatory community, and intertwines that monumentality with an authenticity that situates the self. The main component of the

Capitol Complex is a primitivizing, ten-story concrete and marble prism that seems to reave straight from the earth and water, anchored at two edges by the brick hostels stretching diagonally like arms across the vast, flat site.' Kahn's ideas and intentions, embedded throughout these buildings, can be best understood by tracing the design and construction process from the client's conception for the project; to Kahn's reworking of that concept into what he called the "Form"; to his first schemes for the National Assembly Building, hostels, and the surrounding public gardens; to the design development of the site plan and of the National Assembly; to its final design and specifications for its construction.

Figure 6: National Assembly Complex during construction. (source: Gast, 1999)

Figure 7: View of the hostels across the lake. (source: Gast, 1999)

The Plans:

Kahn's vision for the National Assembly complex, of free individuals freely choosing to participate in the governance of the public realm, and his accompanying "form-concept" of a Western-derived, central plan for parliament, might suggest that he was imposing on an unsuspecting culture a political ideal and a formal structure that was tailored, if not to uniquely American circumstances, then at least to ones foreign to Pakistan. That Kahn employed these conceptions as his datum for the National Assembly Building design indeed reveals a Euro-centric attitude. However, in contrast to the Western sources of these initial ideas, Kahn, as he advanced the design toward his boldest form-giving gestures, exquisitely oriented the siting and the composition of the National Assembly Building and hostels to the place and culture they would serve, sculpting and molding his complex to the climate, and especially to the architectural traditions, of the Indian subcontinent. In doing so, he built in a language that was locally comprehensible while remaining modern, laying the ground for citizens to appropriate the complex as an instantiation of their own highest ideals.

In 1962, parallel to the Ahmedabad project, Kahn is commissioned with his largest project, the planning and realization of an entire government center. Between 1971 and 1973 the process is interrupted in the chaos of civil war and the complex, realized only in parts, is finally inaugurated in 1983, nine years after Kahn's death.

The program includes the parliament building with assembly hall, large areas for administration, a supreme court, housing for staff and ministers, a sports stadium, schools, a hospital - that is, an entire city quarter. Kahn articulates two main areas: the Citadel of Assembly as the site for government activity, and opposite, the Citadel of Institutions as a cultural area for the public. He calls them both “citadel” not to insinuate fortress architecture, but in order to transport solidity onto the spiritual aura of the design as a whole. Finally, he adds a mosque to the assembly building, functioning as main entrance.

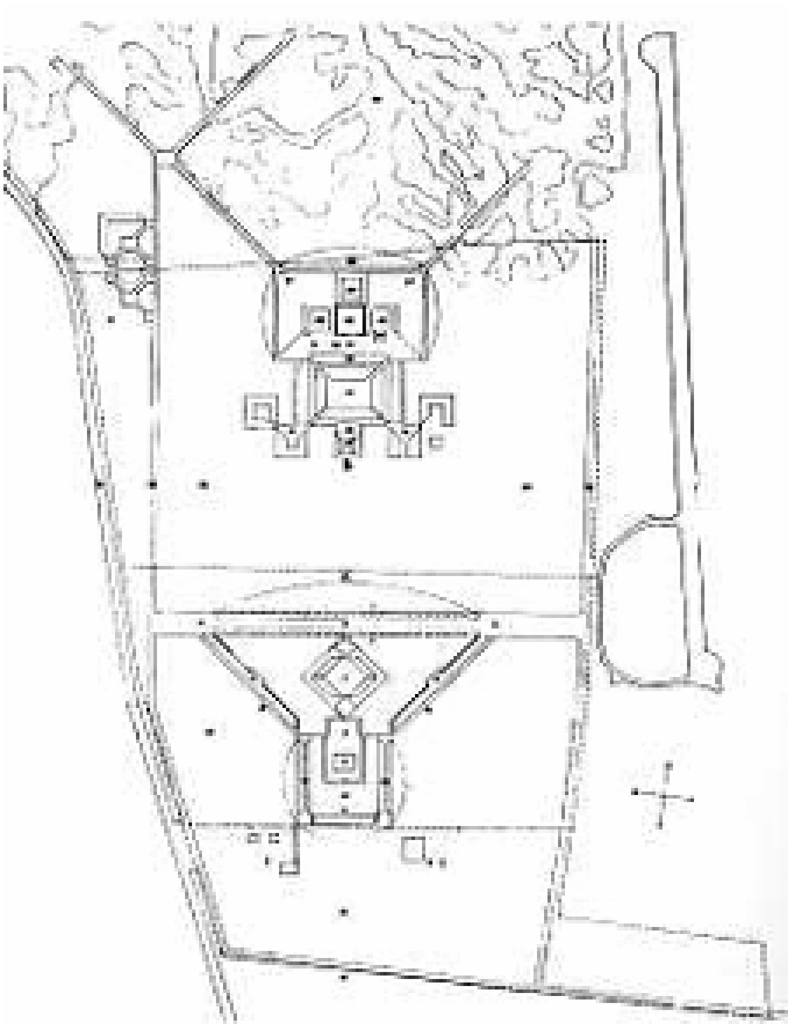


Figure 8: The second site plan of the National Assembly complex, showing the Citadel of Assembly at the bottom, with the mosque at the south tip of the diamond-shaped National Assembly Building, and the Citadel of Institutions at the top, and residences in upper left, May 1963. (source: Goldhagen, 2001)

Kahn's first visit to Dhaka was in January 1963. The basic scheme for the National Capital of Bangladesh sketched at this time shows two groups of buildings facing each other, relating axially: its approximately final disposition was arrived at in December 1963. It demonstrates Kahn's precise conception and his extraordinarily decisive attitude to an idea that fascinated him: that of mastering a very large building mass.

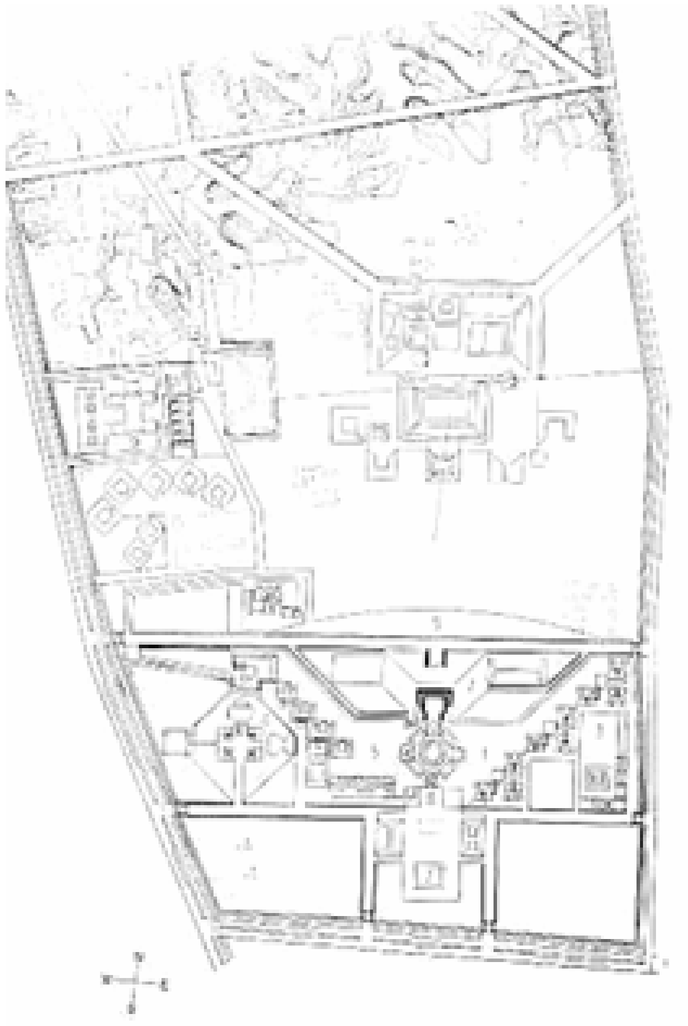


Figure 9: The intermediate site plan of the National Assembly complex, showing the Citadel of Assembly at the bottom and the Citadel of Institutions at the top. (source: Gast, 1999)

By 1964, the building arrangement is fixed and the form of the National Assembly as a "stone" or a "crystal" within an artificial lake, to be diagonally flanked by housing areas, is determined. This and a separate hospital is the only part of the design to be realized. He created a composition at the lower edge of the site with a central prismatic volume as the place for the parliamentary assembly together with linked garden and courtyard areas on two sides and flanking diagonal residential areas.

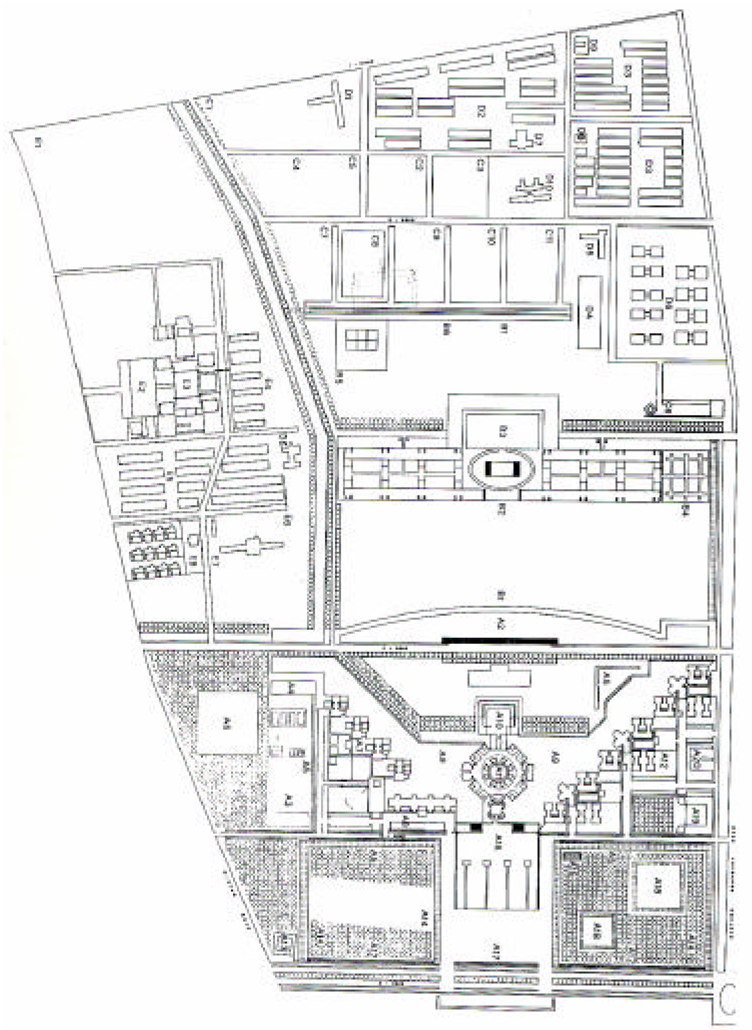


Figure 10: Site Plan, Final version, as of 1973. (source: GA 72, 1994)

Building work on the revised parliamentary complex and the residential zones on each side in fact started in 1964, but the outbreak of the civil war in 1971, difficulties in execution and Kahn's indecision about the roof design for the hall led to a delay of many years. The main building was not approaching completion until about 1982. Nevertheless, a parliamentary city did come into being, complete in itself and strictly hierarchical in its structure, with diagonally linked residences for employees and ministers and public service facilities on either side, gardens and a ceremonial square for the president on the north side as well as the central, crystalline parliament building for 300 members, in the middle of an artificial lake. The parliament building is ringed by four sets of secretarial and ministers' offices, lavish recreation and catering areas and a mosque with its main entrance on the south side.

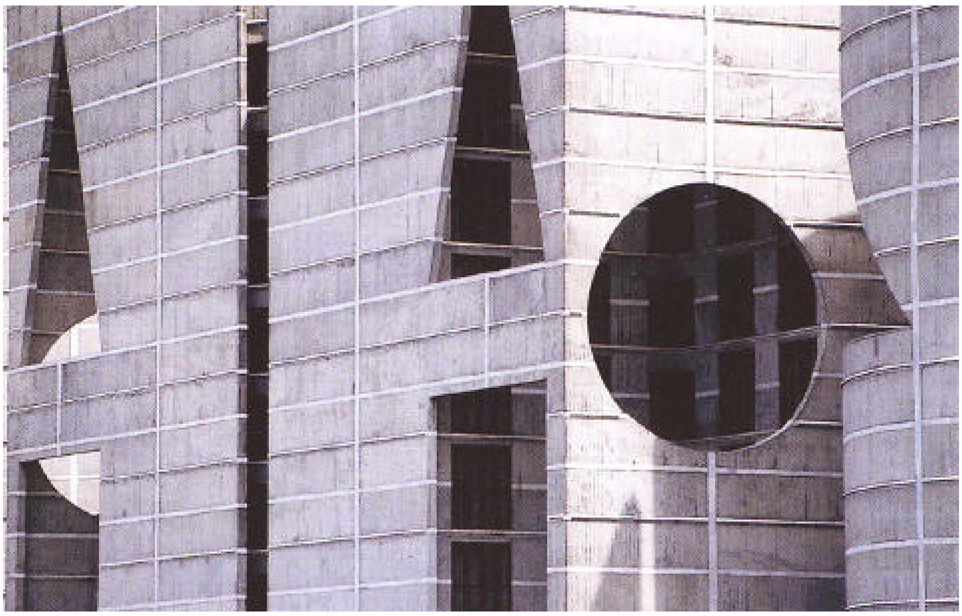


Figure 11: A view of the façade detail focusing the office block and its hollow column.

All parts of the assembly building are built of reinforced concrete, with ordering, strip-like incrustations of marble, and are of the same height. The surrounding hostels with large porches in front are made of brick. This material homogeneity, a motif throughout Kahn's work designating the monolithic, "as if cast in one piece", strengthens the sculptural effect of the buildings. In this type of arrangement, their stiffness is dissolved to the benefit of a suggestively moved ensemble.

CHAPTER THREE ½ THE EXERCISE

Introduction:

The capitol complex project at Dhaka, designed by Louis I Kahn in the late sixties, and finished in the early eighties (though reportedly close to ten thousand drawings were never materialized [Goldhagen, 2001]) exhibits upon closer inspection a host of formal characteristics which are traces of Louis Kahn's innate *geomancy*. An account of the geometrical analysis, with a different approach, of the prismoidal form, the central towering structure, is available in Gast (2001). This example portrays the derivation of the intriguing final geometry (Appendix A) of the form. This enterprise has opened up doors towards further investigation. Kahn's another project in the orient, Indian Institute of Management at Ahmedadbad, India, involved much more interest and extensive analysis from the author in the same book (Gast, 2001). I believe that the project at Dhaka, provided similar depth of interest is taken can also emerge to be similarly delicate and is pregnant with masterly works of hidden geometry. This study is an attempt to exemplify parts of it. As a test case, and due to limitations of time, only the prismatic volume plan is taken into consideration. Figure 15 shows the selected parts.

The most conspicuous feature of Kahn's plans is their seemingly bilateral symmetry of individual units. The selected building is apparently ten storied, with a basement floor. The prime definition of this building is that it is the house of the legislative assembly, or the parliament building. It has a central core that is used as the sitting for the assembly three hundred members of the parliament (MPs), towered by a huge illuminating roof. It also accommodates offices for the ministers and officials. It is at the same time supported by library, lounges, cafeteria, etc., kinds of civic facilities.

The present study concentrates on the boundary of the office block and service core plans and introduces a grammar, which produces a partial plan of these segments in the form of a horizontal section through their facades. The most available plan view (Figure 11, 14) of the building from different published sources account to a drawing cut through the building at forty-eight feet from the ground level. However, plans at different levels may vary in accessibility terms, but the fundamental form is repetitive. Therefore, the plan view at forty-eight feet is taken as granted as a representative one for the building block.

The Shapes in Capitol Plan:

In Figure 12, the rectangular area with a reddish tone outlines the extent of the main capitol buildings with the prismatic volume in the central axis from an image of the final model built for the project. The flanking two arms are the hostels for the members of the parliament. The bluish tone represents the lake surrounding the capitol building. Figure 13 shows the computer generated plan of the selected major buildings here. Our final destination will concentrate more into the building plan of the central prism. Figure 14 is a plan of the main assembly building at the level of forty-eight feet. If we look at figure 15, we can find that there are nine different parts arranged in a radial pattern in the plan, which includes three service cores. In the following, the identical square office blocks, attached diagonally to the central core will be analyzed. Interestingly, it is observed that all the parts in the plan are bilaterally symmetrical against a central axis. In considering the shapes individually, the original axial reference is changed to a x-y axis for the block for clarity in graphics.

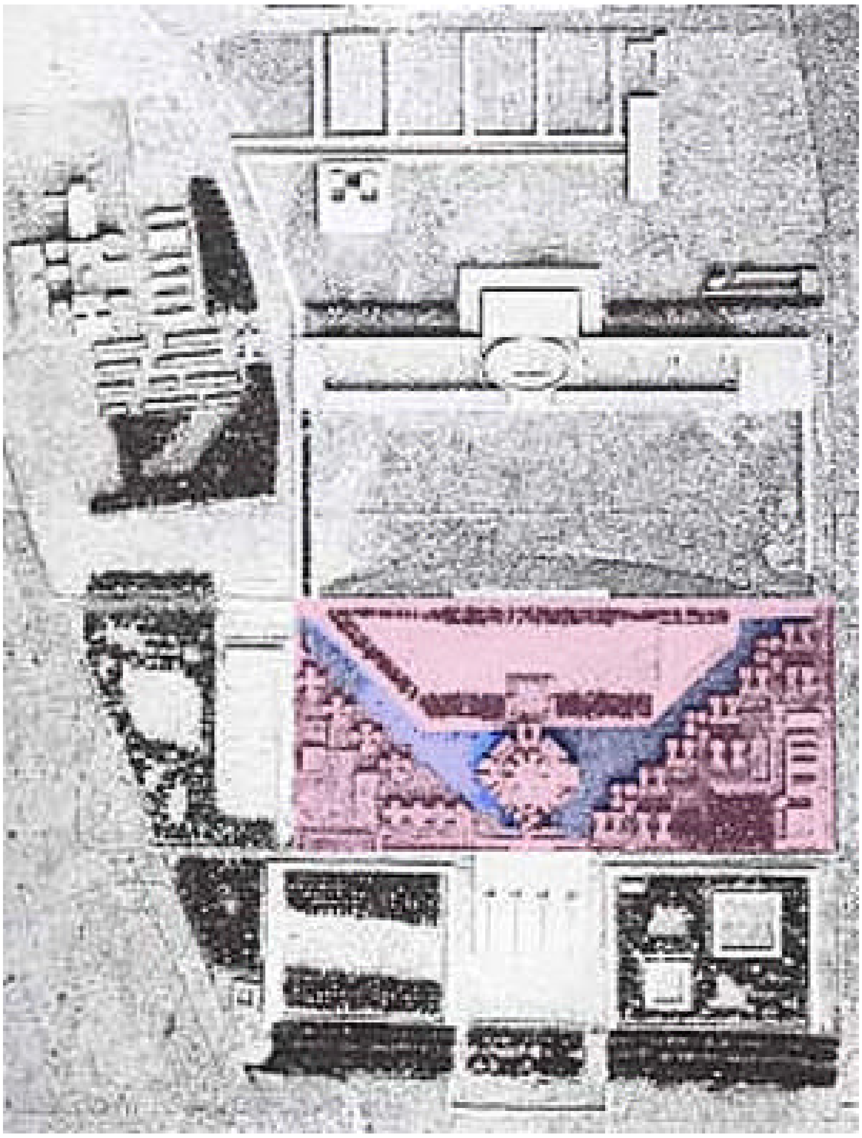


Figure 12: Site model, Final version. (Gast, 1999)

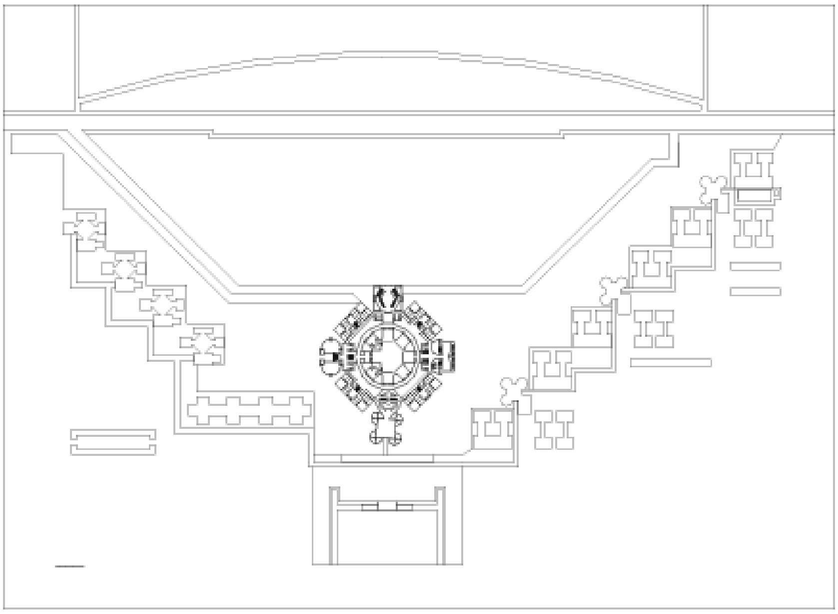


Figure 13: Plan of the Assembly building and flanking MP hostels.

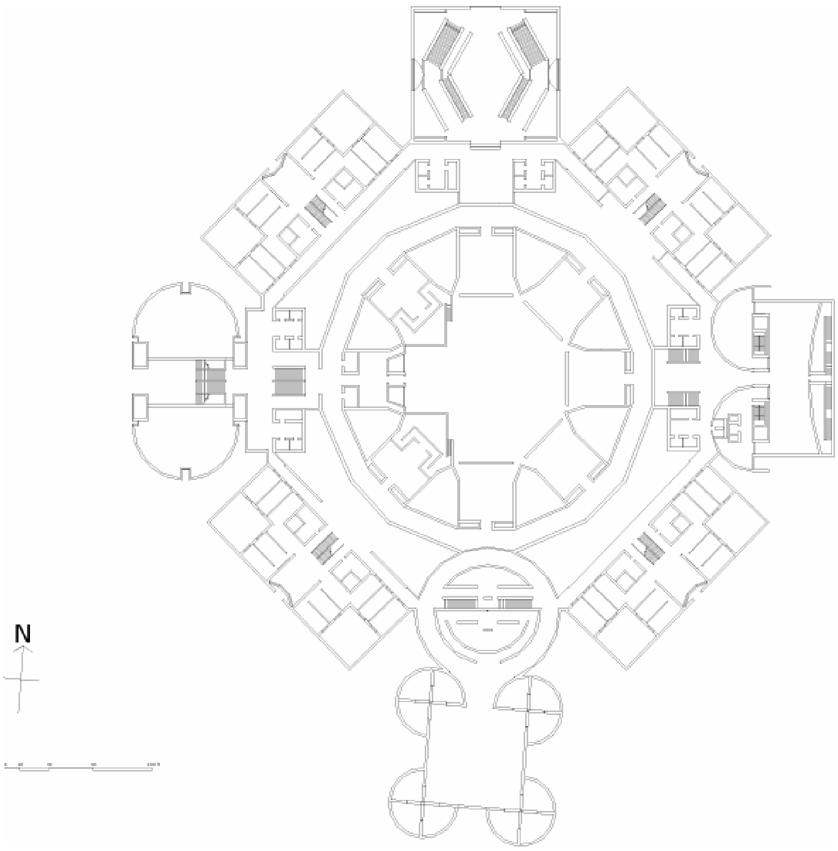


Figure14: Plan at forty-eight feet level of the Assembly building (regenerated).

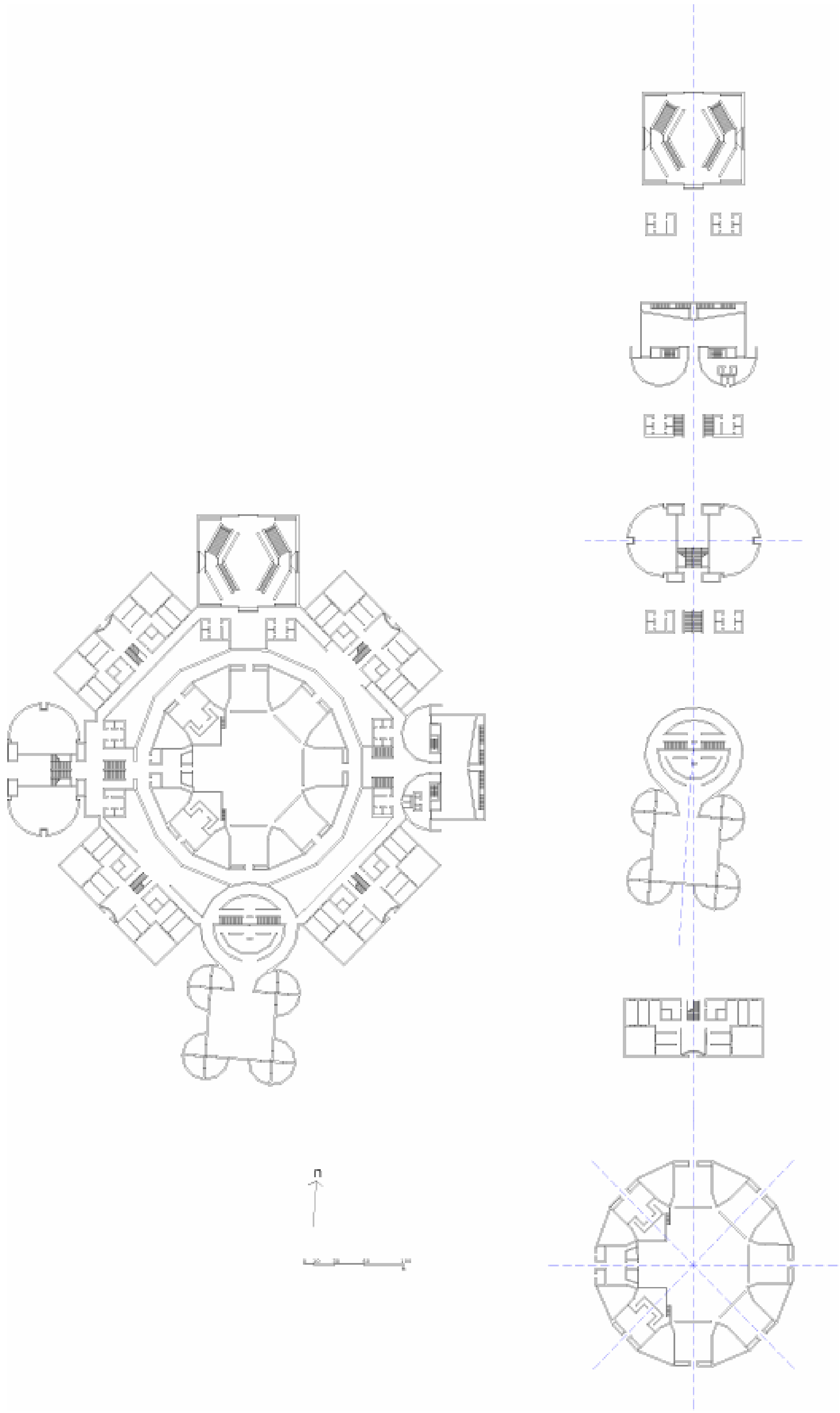


Figure 15: Breakup of different abutting shapes of the Assembly building.

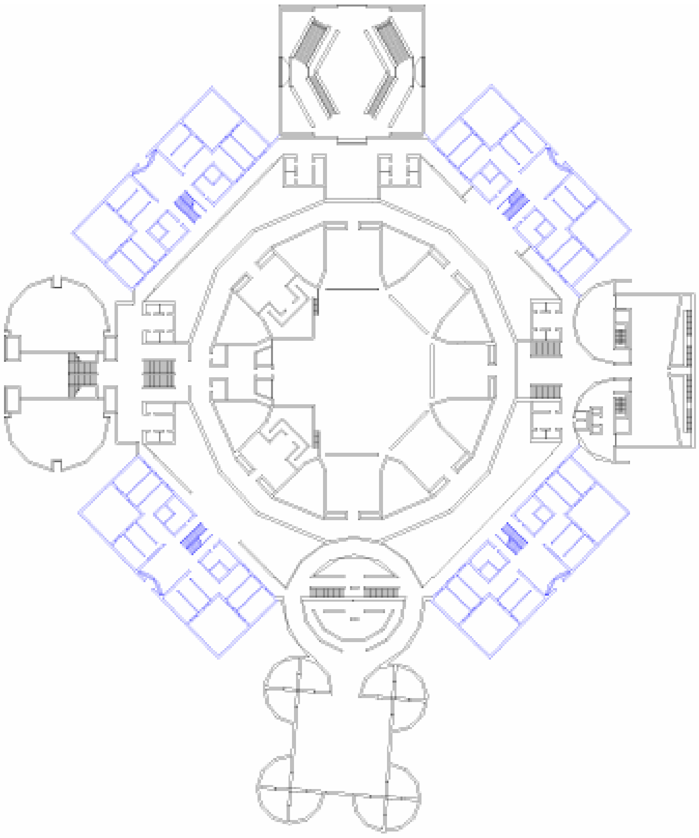


figure 16: Plan indicating the office blocks.

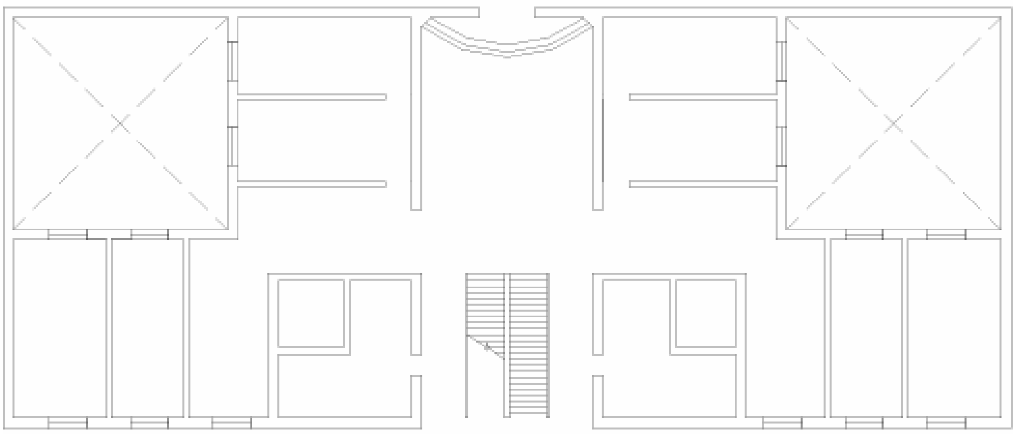


Figure 17: Office block plan.

Grammar Formulation:

The grammar itself is formulated as a parametric shape grammar and follows the general model given for such grammars in Stiny (1980) and also is referred to the first chapter of this thesis. The presentation was modeled after the Palladian grammar described by Stiny and Mitchell (1978) and The Secret of the Casa Giuliani Frigerio by Flemming (1981), who divide the design of a plan into distinct stages and rely extensively on labeled points to signal the transition from one stage to the next.

Shapes are realized in a Cartesian system of coordinates, and the symbols *x* and *y* are used to denote, in the usual way, the coordinates of a point in the system. Instead of shape rules, a parametric shape grammar contains *shape rule schemata,* or *schemata* for short; from any such schema a specific shape rule can be derived through an assignment of values, *g,* to the parameters in the schema. All schemata used in the present grammar are fully parameterized; that is, both the *x* and the *y* coordinates of the end points of each maximal line in a schema are given as parameters. It seemed unnecessary to describe the parameters explicitly for each case as long as it is understood that any assignment *g* must maintain alignments of points parallel to the x-axis or y-axis as they are displayed by the graphic specifications of the schemata; exceptions from this principle will be explicitly stated. The plan is rotated from its original juxtaposition in the building plan to satisfy an alignment with the x-y axis.

The Uniaxial Office Plan:

The plans of all the four office blocks fall in this category, because they are all prototypes of the same plan. These plans may be generated in seven stages which correspond more or less to a natural and intuitive design process. The stages are applied in the following sequence:

1. Grid definition;
2. Exterior-wall definition;
3. Room layout;
4. Interior-wall realignment;
5. Exterior opening;
6. Windows and doors;
7. Termination.

Preliminaries:

The unit of measure used by Louis Kahn was FPS(as used in the USA.) The building is made of shear concrete walls with bands of marble strips running all along the perimeter in equal intervals. (Fig.11) In plan, all the load bearing shear walls are of the same thicknes excepting the interior partition walls. But, for graphical reasons and simplification, the thicknesses are somewhat exaggerated and put to one thickness. The geometrical forms or shapes of Kahn's design always bears with the purity. So has happened here. Pure platonic forms or shapes in interwoven meshes are evident in all walks of his design.

Based on these observations, uniaxial office plans are defined in two-dimensional Cartesian coordinate system. Plans are genrated with respect to the north-south axis of this coordinate system. (The convention is followed that walls and dimensions parallel to the x-axis of the coordinate system are 'east-west'; walls and dimensions parallel to the y-axis are 'north-south'.) For easy reference, the axis is indicated in the initial shape, in the schemata, and in the steps in the generation of office plans by a broken straight line.

The initial shape from which all plans are generated by the sequential and recursive application of the schemata specified below is the labeled shape

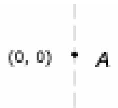


Figure 18: Initial shape.

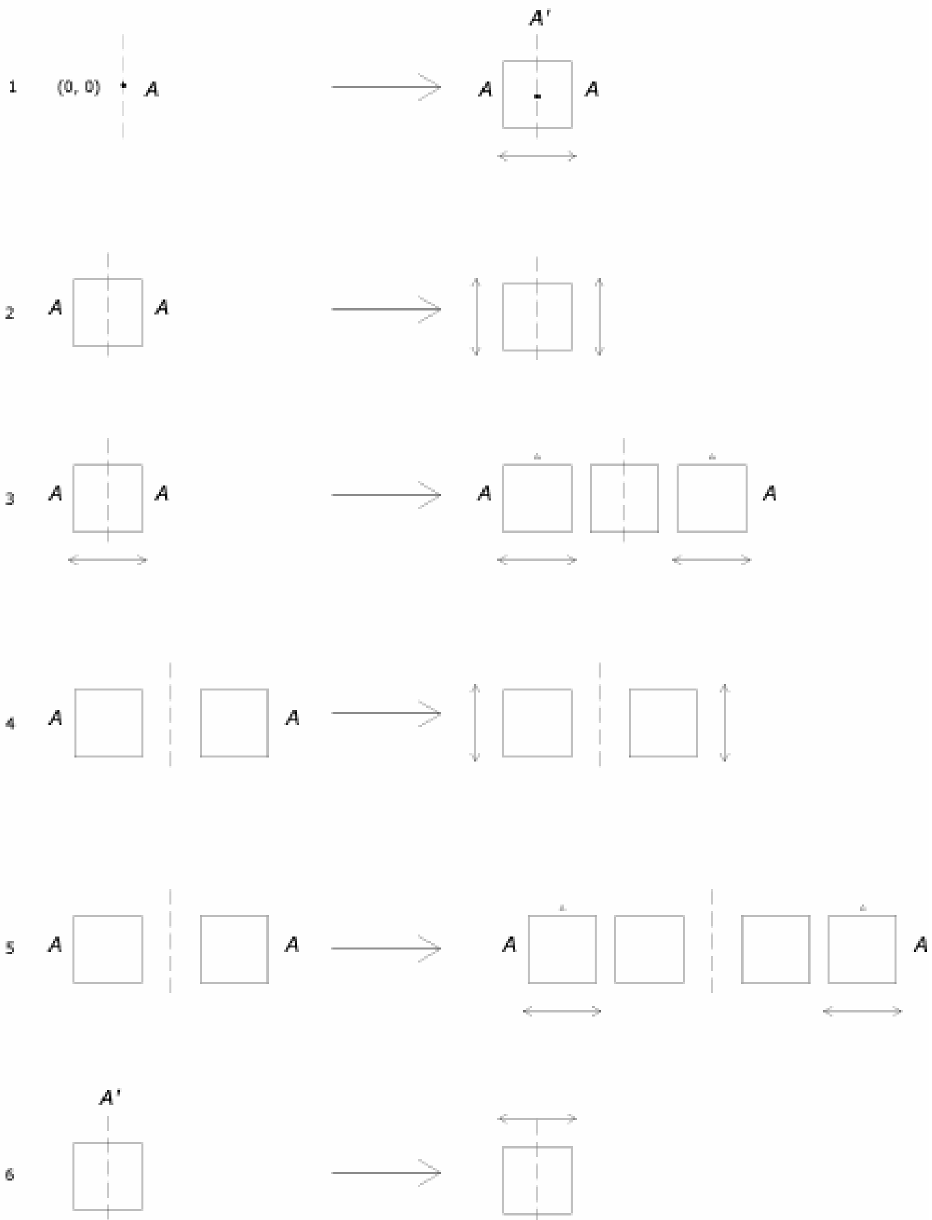


Figure 19a: Rules for generating grids with bilateral symmetry. Grids generated by these rules are used to fix the underlying structure of the office plans. (cont'd)

(s_f, {(0,0): *A}*) shown in figure 18. The initial shape requires that the plans be rooted at the origin of the coordinate system.

In the figures showing the schema or rules for shape generation, the numbers on the left hand side is the index number for the rules. The arrow between two schema stands for the direction of process. The set schemata refers to the theories presented in chapter one of this paper.

Stage 1: Grid definition

The most conspicuous feature of Kahn's office plans here are their bilateral symmetry. Thes eplans are constructed in terms of labeled recatngular grids with bilateral symmetry relative to the north-south axis of the coordinate system. The grids are generated using the rules specified in figure 19a and 19b.The grid required for the layout of the ground plan of the office block is shown in figure21.

Every grid generated by the rules in figure 19a and 19b consists of a (2m+1) x n array of variously dimensioned recatngles along the x-axis and 2m x n array in the y-axis, where m and n are integers such that m/0 and n∃0.

In each grid, the central column of rectangles is bisected by the north-south axis of the coordinate system. Each rectangle to the left of the axis has a corresponding reflection to the right of the axis. Adjacent rectangles in the grid are separated by a fixed distance of one wall thickness; their parallel edges are the same length. The dimensions of these rectangles are determined by the assignments used to apply the rules that generate the grid. Usually these dimensions are small integer multiples of the unit measure. The line segments, with arrowheads at their end points, surrounding the grid are used to record the original dimensions of its component rectangles. These dimensions are used mainly from stage 5 onwards. In order to ensure bilateral symmetry, to fix wall thickness at a

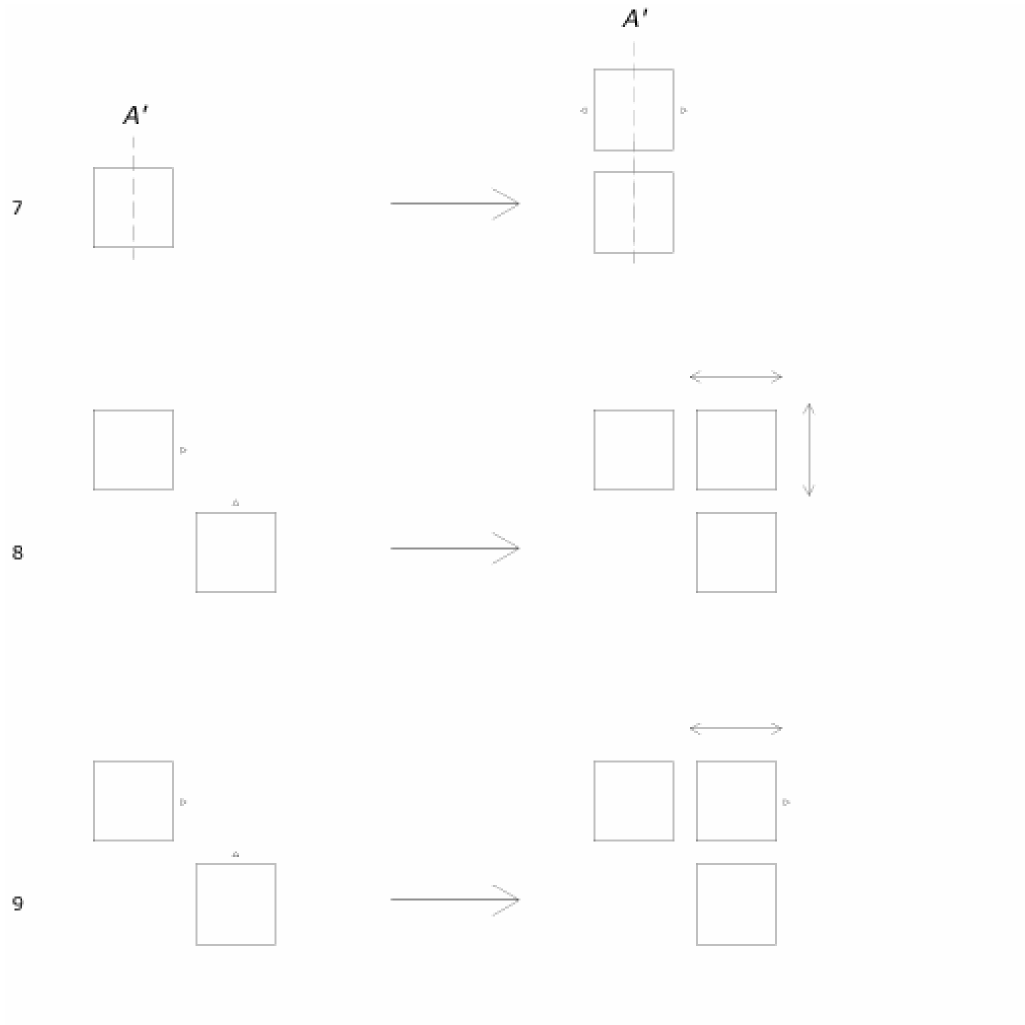


Figure 19b: Rules for generating grids with bilateral symmetry. Grids generated by these rules are used to fix the underlying structure of the office plans.

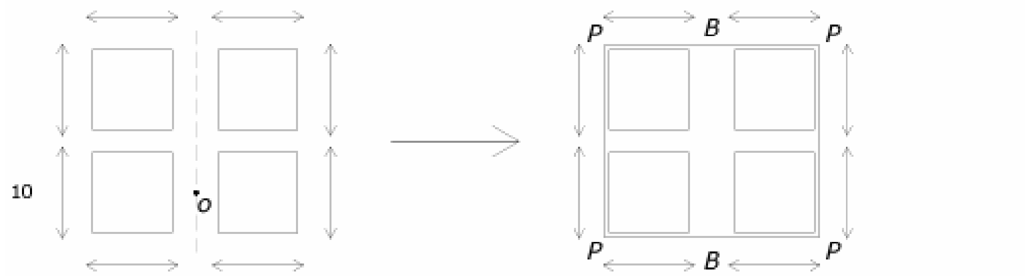


Figure 20: Rules for the generation of exterior walls.

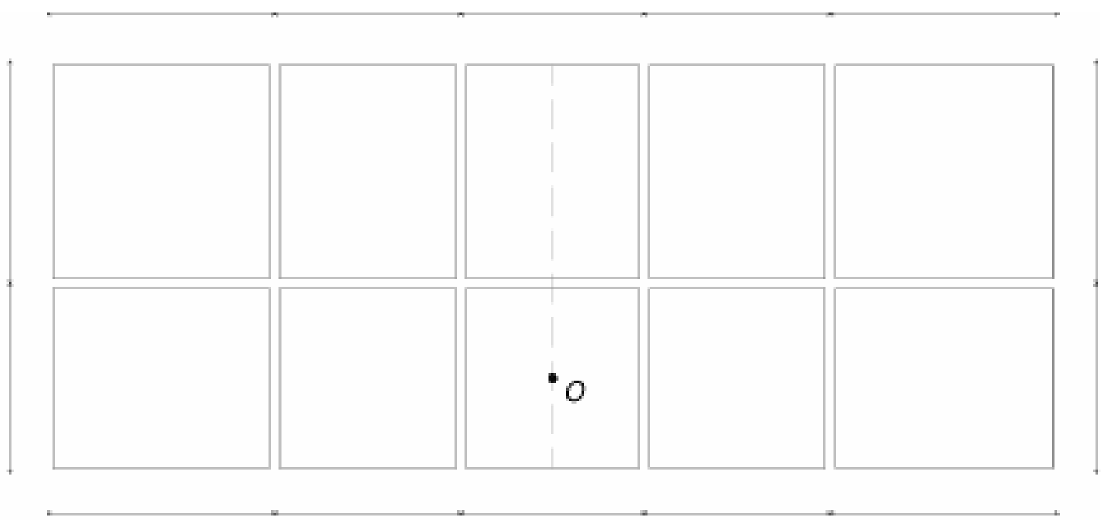


Figure 21: The underlying grid generated for the office block.

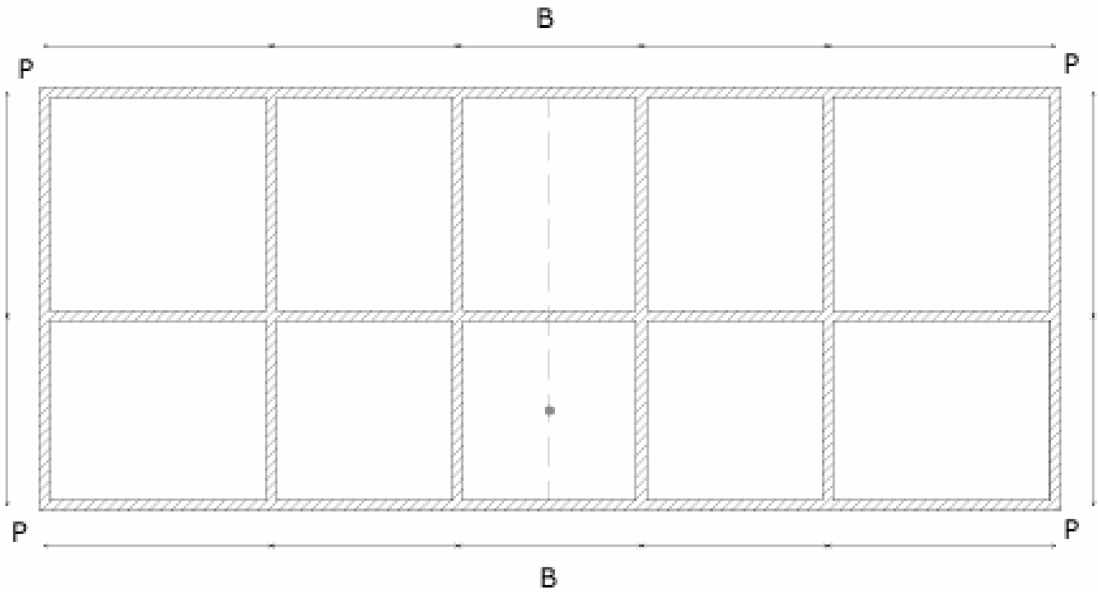


Figure 22: The underlying wall pattern for the office block.

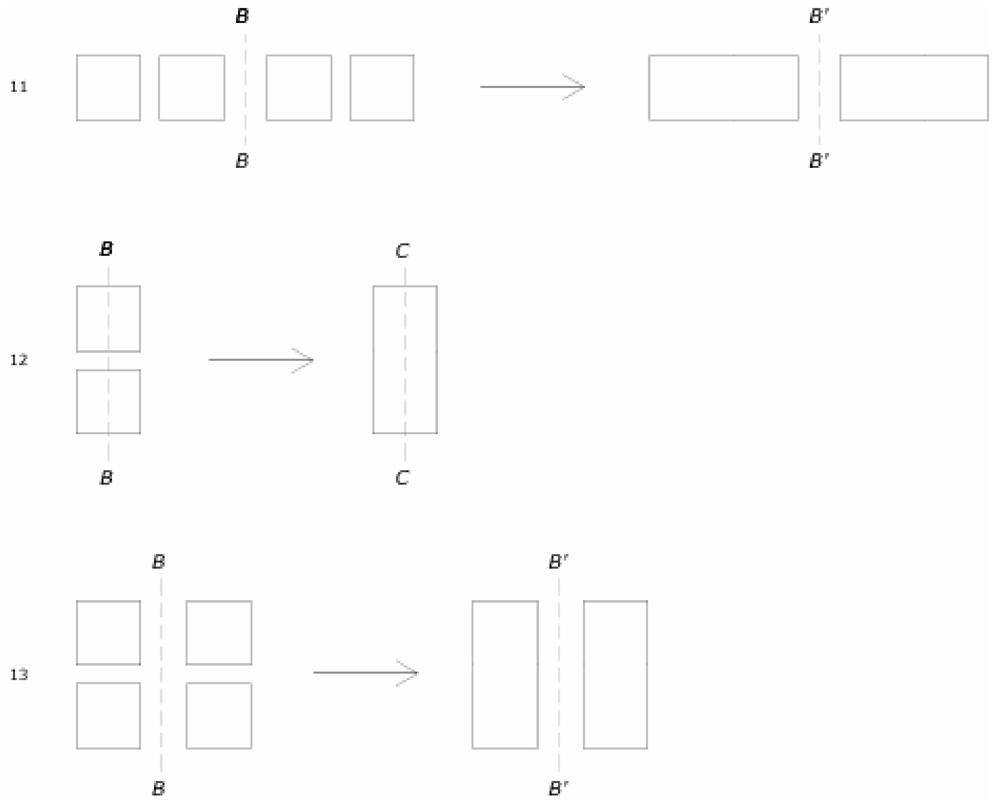


Figure 23: Rules for room layout.

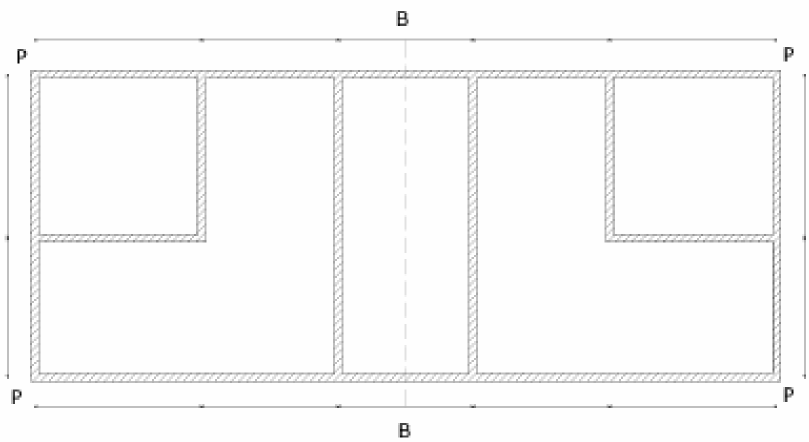


Figure 24: Generation of room layout for the office block.

constant value, and to incorporate proportioning rules simultaneously, it is necessary to associate parameters and parametric expressions with the grid generation rules and with the rules specified in the following stages. The parameterization of rules in this first stage is the most critical. Once a grid has been generated, it constrains all subsequent applications of rules in such a way that their associated variables are forced to assume the correct values. Any consistent well-defined set of dimensioning and proportioning rules can be incorporated into this grammar by parameterizing its rules.

Stage 2: Exterior-wall definition:

Once a grid is generated, it is circumscribed by a rectangle to form an exterior wall. This operation is performed by the rule specified in figure 20. The underlying wall pattern generated for the office plan by applying this rule to the grid in figure 21 is shown in figure 22. The walls in this drawing are hatched.

Stage 3: Room layout:

The interior spaces in Kahn's chosen office plans may be rectangular, I-shaped or partially L-shaped. Rooms with these shapes are formed by recursively concatenating the spaces in the wall pattern generated for a villa, in accordance with the rules specified in figure 23. Applications of these rules preserve the symmetry of the plan. It is to be noted that a plan can have at most one nonrectangular space and that this space cannot be bisected by the north-south axis of the coordinate system.

The generation of the room layout for the office is given in figure 24. The drawing in this figure is produced by applying schema 11, 12 and 13 to the wall pattern in figure 24.

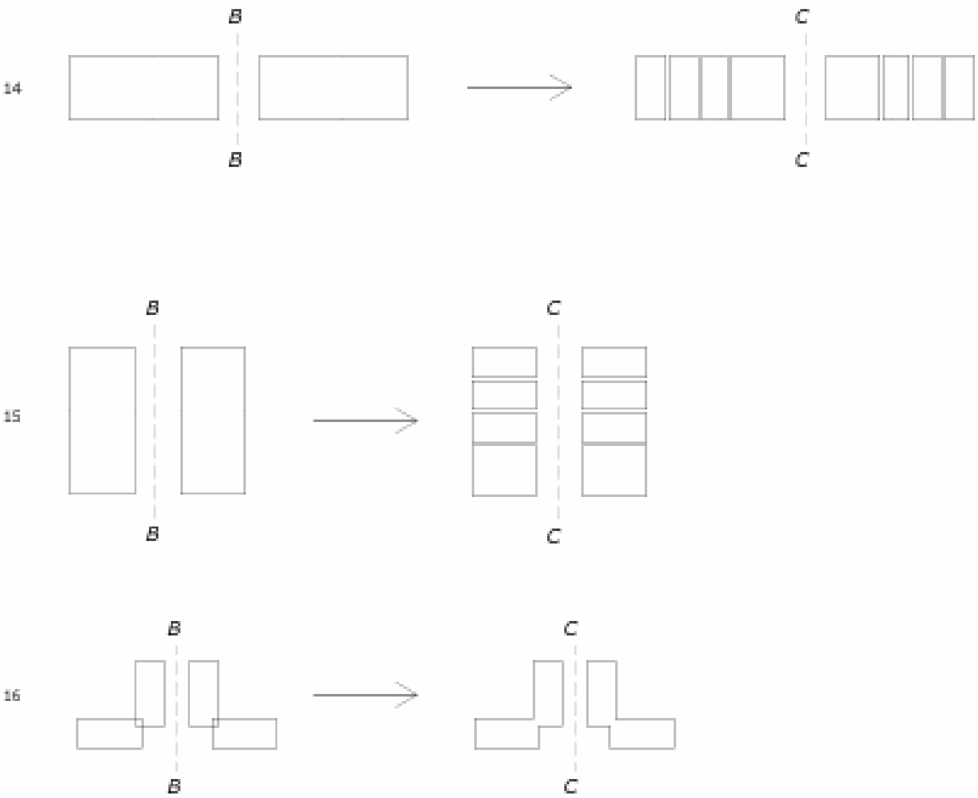


Figure 25: Rules for realigning interior walls.

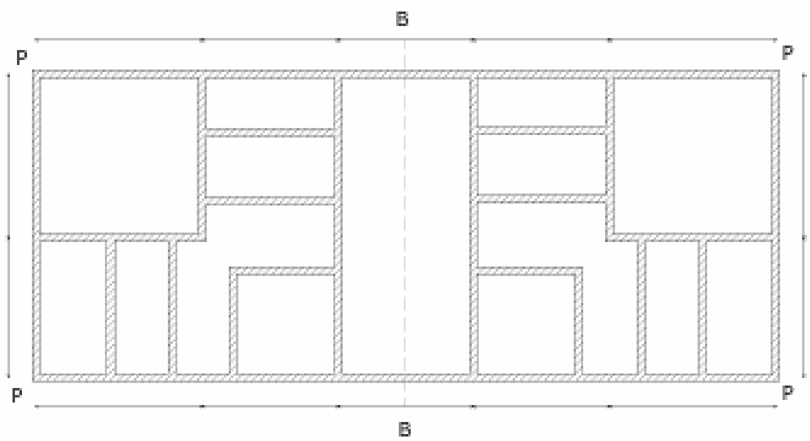


Figure 26: Generation of room layout applying realignment schema.

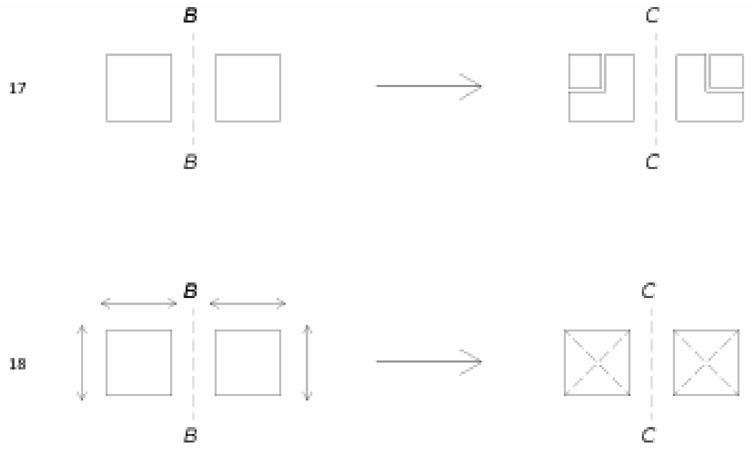


Figure 27: Rules for realigning interior walls. (cont'd)

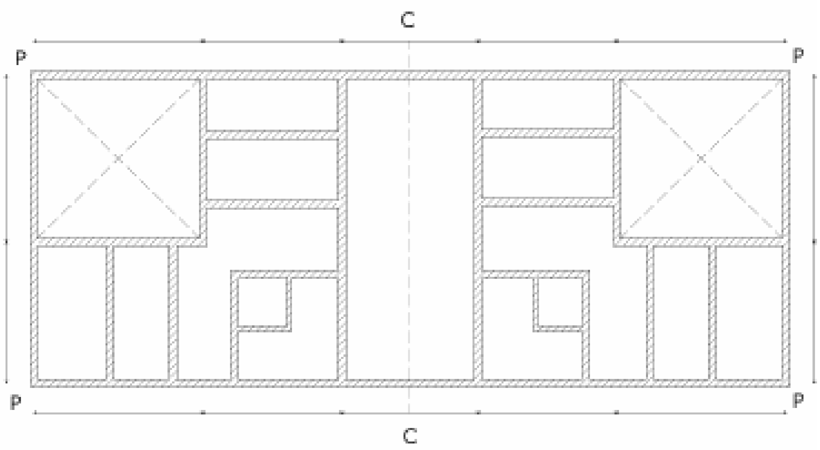
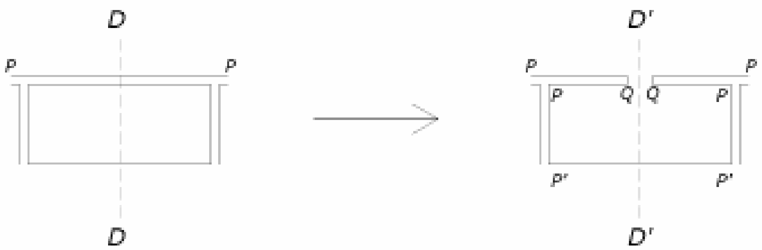
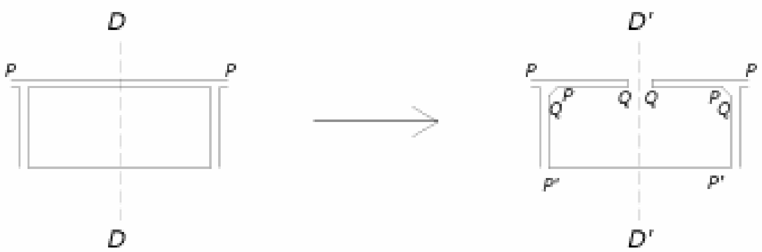


Figure 28: Generation of room layout for the office block. (final stage)

19 $\langle s_a, \{(0, 0)\}: C\rangle \rightarrow \langle s_h, \{(0, 0)\}: D\rangle$

20


21


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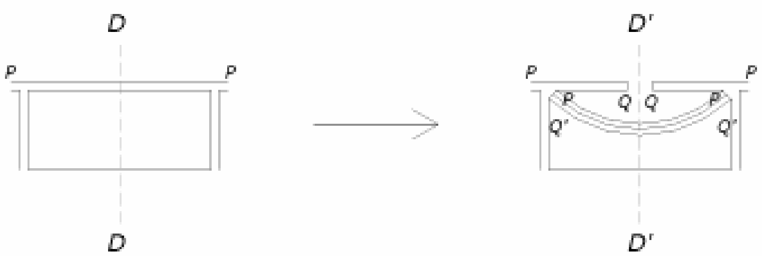


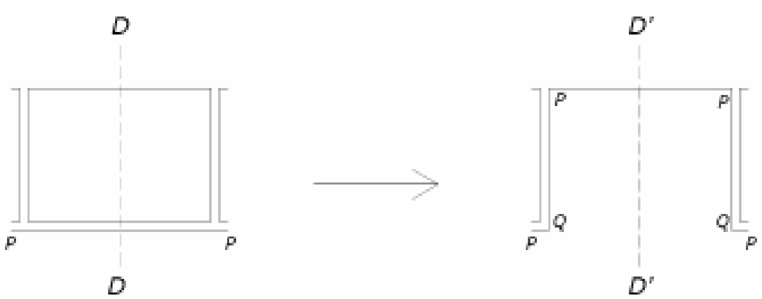
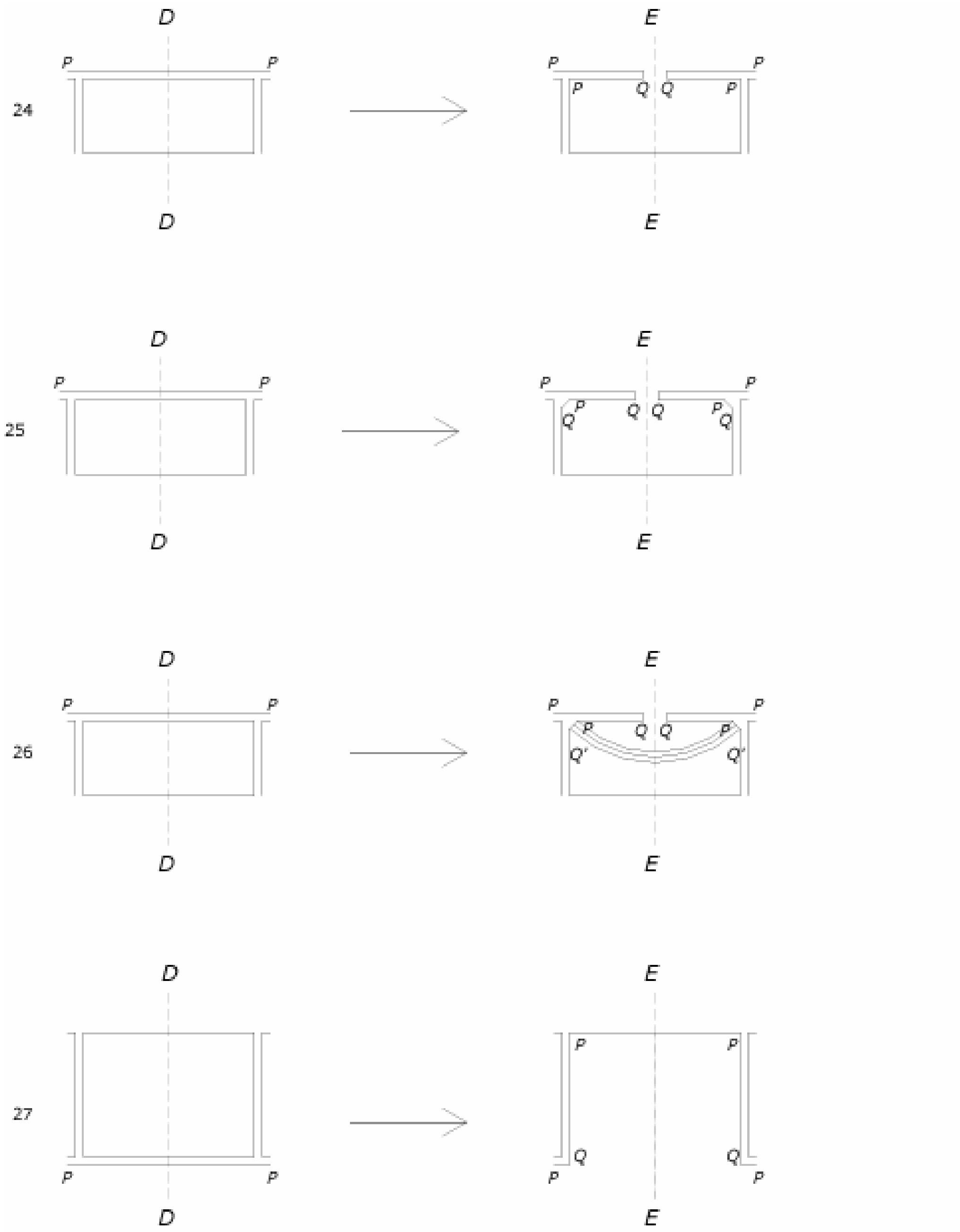
23


Figure 29a: Rules for wall inflections and opening in the shear wall to direct exterior.



28 $\langle s_{\phi}, \{(0, 0)\}: P' \rangle \rightarrow \langle s_{\phi}, \phi \rangle$

29 $\langle s_{\phi}, \{(0, 0)\}: D' \rangle \rightarrow \langle s_{\phi}, \{(0, 0)\}: E \rangle$

Figure 29b: Rules for wall inflections and opening in the shear wall to direct exterior.

Stage 4: Interior-wall realignment:

North-south and east-west shifts of internal walls away from the underlying grid are used by Kahn to make minor adjustments to room layouts. The rules specified in figure 25 and 27, produce these wall realignments in all cases; they apply to room layouts generated in stage 3. The application of these rules preserves the symmetry of the plan. Figure 24 and 26 are resultant interior room layout and wall alignment for the office plan with the application of schemata through 11 to 16.

Schema 17 and 18 account for a special kind of treatment used by Kahn in his designs. Schema 17 shows the choice of space to create the 'hollow column' in the plan, extensively used in plans through out Kahn's design in the east. This, Kahn referred to as putting a wall inside a wall as to creating a curtain from glare and the harsh climate in these areas. We can recall the use a *brise soleil* by Le Corbusier in his designs in India. These hollow columns prevents the use of direct exterior windows to be placed on the façade and thereby creating massive primary openings on the façade to augment the grandeur of the built form as a whole. This technique is of course reminiscence of Kahn's other public buildings in the west, only to be different in scale.

Stage 5: Exterior opening:

As explained in the previous paragraph, Kahn's use of hollow columns prevented from openings to direct exterior from room interior. In all his precepts, Kahn has used some sort of curtain to create a buffer between the two. A more detailed understanding is possible if exterior façade is taken into consideration for analysis. Due to limitations, I am concentrating on the opening on the far end of the y-axis. This treatment is exemplified in the schemata 20 through 22. The use of an arch shaped window is though unique only in this case of the plan, but not in the drawings of the whole complex.

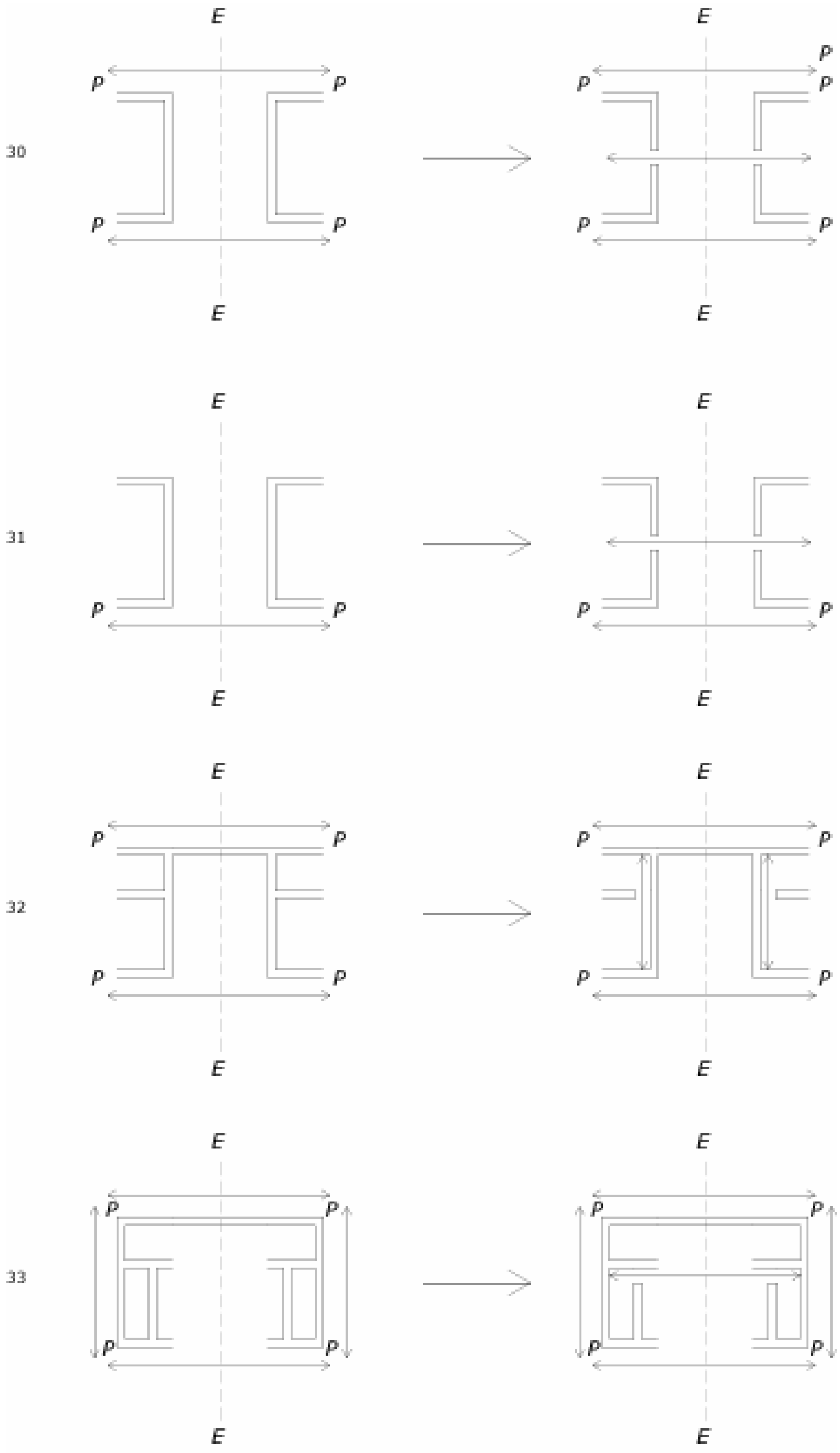


Figure 31a: Rules for locating windows and doors in office plans.

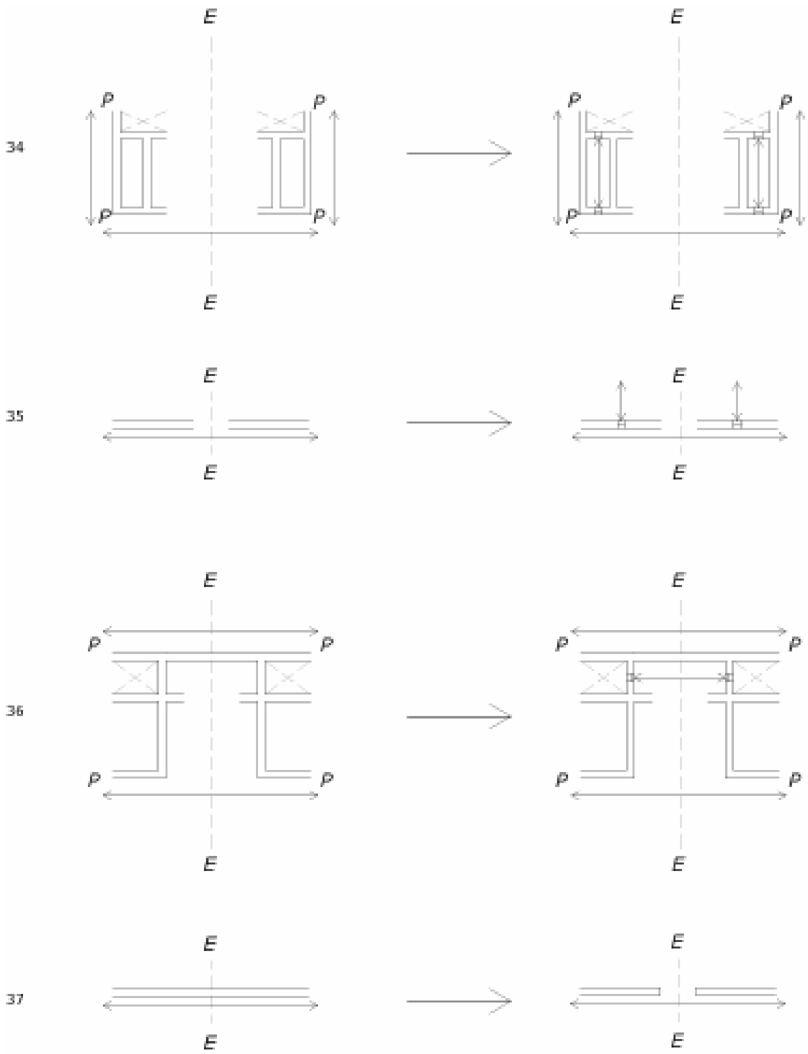


Figure 31b: Rules for locating windows and doors in office plans.

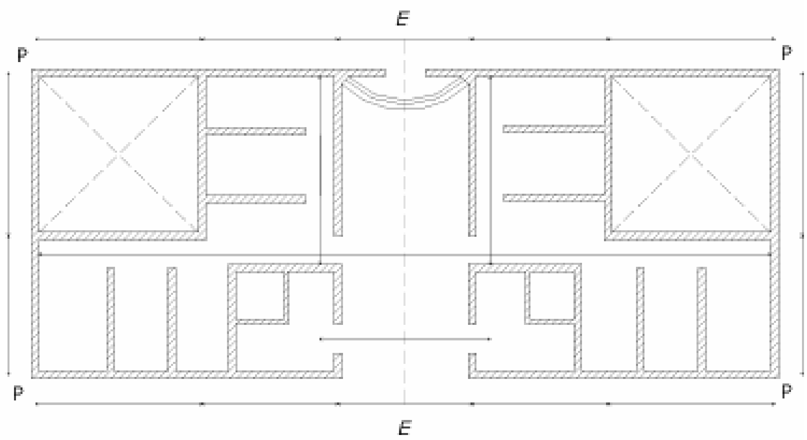


Figure 32: Generation of doors in the office plan.

Figure 30 shows the generation of the linkage between interior and exterior space.

Stage 7: windows and doors:

Schemata 30 through 33 specified in figure 31a fix the conditions under which doors can be inserted in the office plan. These doors occur on both sides of but not on the plan's axis of symmetry. One such opening is inserted in each nonaxial interior-wall segment corresponding to a north-south or east-west dimension of one of the original rectangles in the underlying grid for the plan. Exterior walls are distinguished by occurrences of the label *P*; the line segments, determine their component parts with arrowheads at their end points, surrounding the plan. Typically, doors are located at one end of its length, probably from functionalist approach, only with the exception of the door near the entrance.

Rules 34 through 37 in figure 31b allow for nonaxial interior windows to be located in a plan symmetrically so that they line up with previously inserted doors in a right angle form of formation with each other. A door can be placed in a wall just in the case when it is not a direct exterior wall. Windows can open up along the inner wall of a hollow column or the interior wall (with respect to the building plan). Windows are placed centrally on the length of an interior wall segment. Because of the use of hollow columns, no exterior windows can be seen in the elevation. (Figure 11)

It can be noticed that the central axes of the doors and windows are never aligned and always intersect at right angles. In this way, the characteristic *enfilade* is produced. (Figure 33)

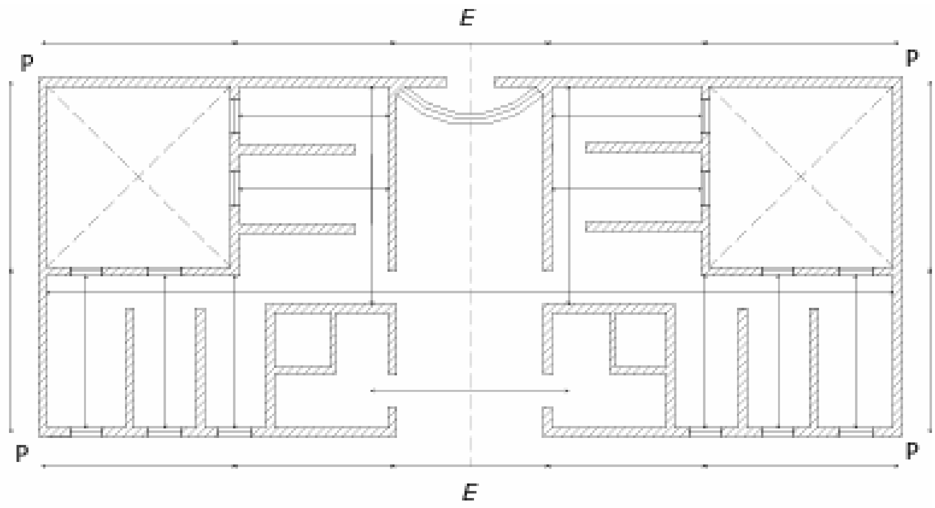
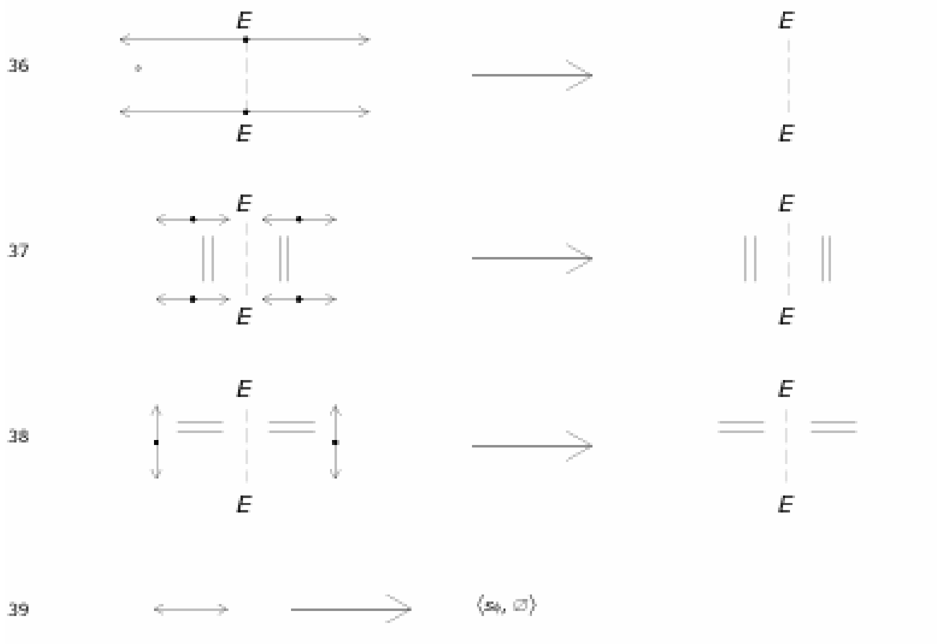


Figure 33: Generation of windows in the office plan.



40 $\langle s_4, \{(0, 0)\}: P\rangle \rightarrow \langle s_4, \varnothing\rangle$

41 $\langle s_4, \{(0, 0)\}: E\rangle \rightarrow \langle s_4, \varnothing\rangle$

Figure 34: Rules of termination.

Stage 8: Termination:

Termination rules are specified in figure 34. For the most part, these rules provide for the erasing of the labels and labeled line segments (line segments with arrowheads at their end points and possibly the symbol • at their midpoints) used to guide the plan generation process. Notice that the labeled line segments, with arrowheads at their end points, which surround a plan, can be erased if and only if there is an interior-wall segment associated with them (schemata 39 and 40). These rules ensure that some part of each wall in the underlying wall pattern generated for the office block (stages I and 2) remains in the final plan. For this condition to be satisfied, the grid for the plan must be minimal. Only plans which have been correctly generated in the previous six stages can have all of their labels erased. These unlabeled plans are in the language of office plans (in the Capitol building) defined by the parametric shape grammar given here. The final plan generated for the office block is shown in figure 35.

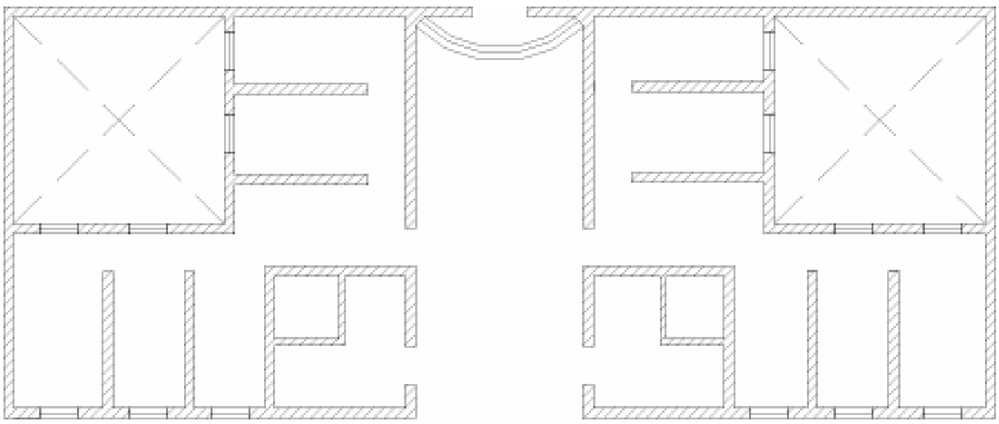


Figure 35: The final plan generated for the office block plans.

Figure 36: Process of generation of the final plan.

Discussion:

The results achieved here portray a matrix of rules or schema Kahn has used in the design of the office block in the capitol building. The grammar presented here expresses principles through schemata, which are simple in double sense: (1) each schema defines only a very limited range of properties, and (2) it influences only a small portion of a shape.

However, now the question arises, what we can learn from this study. How to use shape and shape grammars has been being dealt on for several years from its very birth. 'Decidability' of shape grammars and their non-deterministic qualities had been discussed in her paper by Knight (1999a, 1999b). Nevertheless, this study is not focused on the verification of shape grammar formalism. Shape grammar is definitely a learning tool that helps us understand the design matrix underlying a design. However, at the same time it is a design tool too. They seem to intermingle in the process of creation. This overlap, I believe, is not detrimental a design tool for the learning and designing process. The precepts learned from here can very well be implemented in the texture of the urban design of the area this project hails from. I also believe that this approach will open doors to the readers who appreciate works of Kahn and long to know the secrets of his endeavor, in a quantitative way.

Conclusion | Observations

The history of shape and shape grammar is not very old. Many approaches in order to analyze a corpus of design have been developed. Only one is being used here. An application of other methods can wield different results, but will not break the fundamental fabric developed here. The parametric shape rules illustrated here are created on an instinctive and logical way of approach. Nevertheless, it is a subjective method to some extent. However, this paper has introduced Kahn's design from a new perspective, which calls for further research in this line.

The results show us a newer fabric woven into the design of Kahn, in a partial way. A more elaborate study can evolve newer aspects in the works of the master. Kahn has been studied and still being studied by the intelligible class in various perspectives. As I can remember one remark by a student, "if Corbusier is a gift to architecture from the land of magicians, then Kahn is a gift to architecture from the land of philosophies". A land of philosophy that instills an aura of delicate geomancy into the minds.

The study conducted here is analytical. It breaks up the design plan into standardized piecemeal to find out the skeletal form. This process helped us understand the beauty in Kahn's approach in design. "Order is." Was the definition of Kahn when asked to define 'order'. The answer is explicit and evident when we analyze his works, just as this study conducted here.

Conclusion | Future Research

Designing is a process of deciding what is best out of an array of possibilities. A designer develops a personal relationship with a design tool, leading to an individual belief in his/her experience with the tool. However, a designer's fluency with a preferred design tool or method is usually not vocalized. With reference to shape grammars, and their place in the design process, it can said that when a designer becomes fluent in using particular tool he/she is able to better consider all the possibilities available to her. Different exploratory microworlds are needed to derive a better understanding of the objects that are being created. The designer will

develop his/her own criteria for using different microworlds, which could include convenience and how that environment relates to the particular stage reached in the design process. Shape grammars provide one particular microworld, or technical domain, for design exploration.

In the recent years, the approach to deal with shape grammars have changed and taken a new shape. Computational design has evolved to be a new design tool for the workbench. *Shaper2D*, a software to develop shape grammar into an interactive design tool is developed in the MIT. In this time of information age and available technology, shape grammars could evolve as a veritable form of analytical and design tool.

From a different point of view, when the algorithm developed from an analysis of shape grammars of a particular design, it can work as a defining parameter for a style or corpus of design. One of my beliefs is that, this algorithm can be obtained to be used a comparative assessment tool for a design work to judge its 'contextuality' or the 'out of placeness'. This may invite contradictions with the question of necessity. However, I strongly believe that economic globalization cannot embody cultural and/or heritage into its periphery, so cannot architecture. This tool will act as 'microworld' for the contextually motivated designers.

APPENDIX A ½ GEOMETRY IN CAPITOL PLAN

Foreword:

Contradictions remain an essential component of the architecture in Dhaka. Kahn consciously uses them as means of building up inner tensions, like the calculated move away from axial symmetry evoked by dynamic processes, the distortion of basic geometrical figures and diagonally shifting elements. This not only has an effect on the disposition of the ground plan, but also shows views of the buildings as an ensemble that is compact, yet moving, almost "dancing" around a center, particularly as the viewer continues to move. The contrasts of divided and linked partial figures, massive cubes against perforated membranes and the combination of both noble and ignoble material, in order to enhance the claim of autonomy in terms of the functional linking also enrich the repertoire. It becomes clear from the following analysis of the parliament buildings that Kahn followed very consciously the above-mentioned process of distorting his original figures of square and circle. The genesis of the design, in the process shown here, illustrates how Kahn fought to balance the retention of pre-existing forms and the creation of a more complex geometrical structure.

Analysis:

[Figure A1]
The starting figure for the parliament building is a square standing on its tip. It defines the shape of the building as a kind of frame. The entire genesis of the basic figure ensues within this frame as a geometrical process comparable to biological development. Axial relations are important here, in this case not as parallels to the sides but as diagonal axes. They set the "genetic" directions in this figure.

Note: The text and graphics are extracted and compiled from Gast (2001), for referential usage only.

[Figure A2]

Zones are defined by a grid structure made up of nine squares within the starting figure. This figure of division into nine also pre-exists as far as Kahn is concerned, as it is a simplified primal figure of the above-mentioned *mandala*, and a motif that runs through all Kahn's work. Structure and a diagonal axial cross form the essence, a *genetic scaffolding* from which more complex subsequent figures emerge.

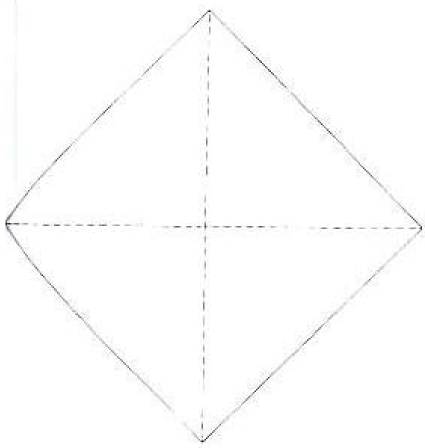


Figure: A1

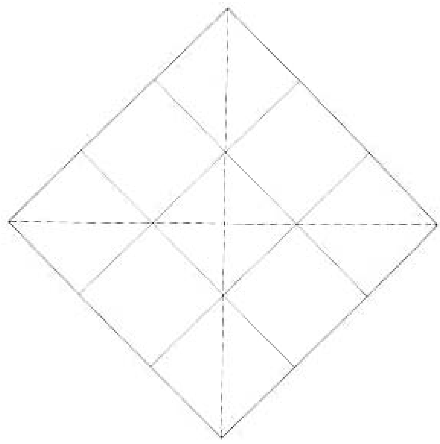


Figure: A2

[Figure A3]

Half the length of a diagonal is now divided in the proportion of the Golden Section. Its geometrical structure can be explained as follows: the half diagonal forms an equilateral triangle with its central, halving vertical. Half its hypotenuse, as an arc of a circle, cuts the arc of the short side of the triangle (cathetus). A line runs through this point of intersection, dividing the half diagonal in the ratio described. The shorter section of this division forms the minor Golden Section, radius of a circle developing around the central point. This is the center and becomes the starting figure for the inner hall building.

[Figure A4]

The next thing to emerge is the geometrical connection between the framing outline of the square and the central circular figure. The arc of a circle with the side length of the square cuts the diagonal at a point that is its root 2 division, and thus defines a new radius of a circle that surrounds the inner circle. Golden Section and root 2 proportion once more appear, as in all Kahn's designs, as a communicating pair and form a tense and irrational element within the rationally developed basic structure.

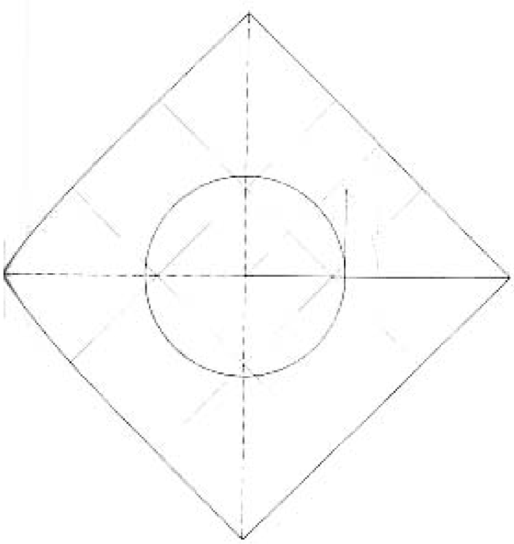


Figure: A3

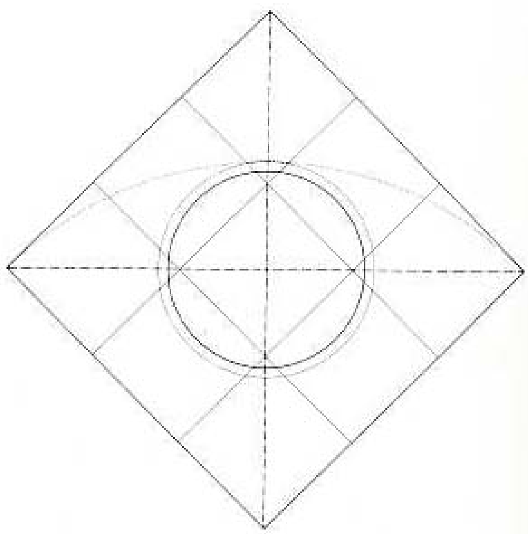


Figure: A4

[Figure A5]

The crucial process that lies behind the whole structure of the parliament building is that the inner circle, enlarged by the thickness of a wall, is now *exploded.* It extends in a north-south direction by a distance that is determined by the outer circle. The tangents at the points of intersection with the vertical axis fix the distance between the circles in the way they cut the outer circle at two points in each case. Thus, the original circular figure of the hall building develops into a form like an oval and suggests a distortion process with centrifugal forces, although they are directed in this project, in contrast with the usual equally undirected forces. Not only the circle is distorted, but the axes parallel with the sides that are associated with it also shift together with the two centers of the radii in a north-south direction.

[Figure A6]
It is remarkable so as to the framing outline of the square, does not change with the extension of the circle in the center of the square. All the processes of movement up to this point have taken place within the bounds of the square and retain the original figure in its totality. Another root 2 division can now be constructed with the shifted axis positions and their slightly changed lengths. The axis forms the diagonal of an imaginary square, the length of whose sides cuts the diagonal as the arc of a circle. Here a line running parallel with the sides of the initial square is added: this forms an outer peripheral zone and divides the area of the square into three fields: an outer "ring", the oval figure in the center and a gap that is not further defined.

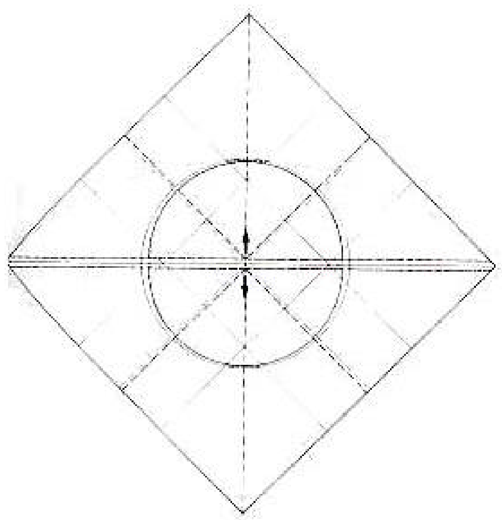


Figure: A5

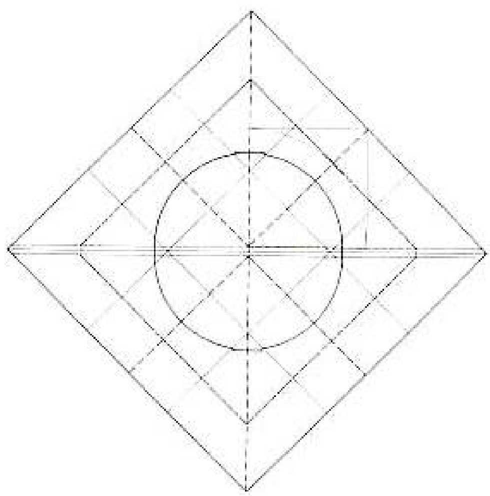


Figure: A6

[Figure A7]

Starting from the grid structure of the square's division into nine, fields that can be clearly outlined are defined within the outer peripheral zone, showing up as four similar rectangles. They make up the administrative areas for the parliament. It is quickly clear that these zones are also shifted together with the axes, so that although the vertical and horizontal axes of the starting square retain mirror symmetry, the orthogonal opposite in each case shows differing positions. The long side of such a rectangular area corresponds to the division of the starting square into thirds. The short side allows outer squares to be divided off, to be used as the actual offices.

[Figure A8]

As well as the office areas, we can assume that the other zones also started as rectangles in Kahn's design ideas. At this stage, Kahn sketched rectangles arranged in a ring, appropriately to the scheme presented. Analysis shows that the three areas on the west, north and east sides are squares of the same size, as adjacent narrow zones of this width actually exist in the realized building as access areas. These narrow access zones overlap partly with the squares whose outer corners bump against the framing line of the starting square.

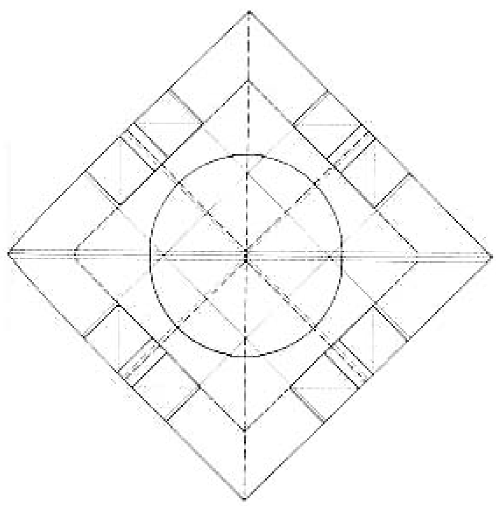


Figure: A7

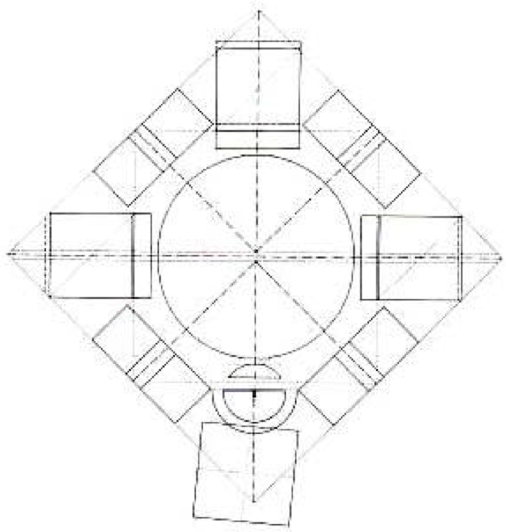


Figure: A8

A circular figure is created in the southern area, which unlike the extending hall figure is compressed, and consists of two segments of a circle with different centers. Extending the central hall circle to form an oval gives the impression that the neighbouring figures are distorted with it, as it were. Here we are dealing with a lavish access element in the zone in front of the separate mosque building. The mosque is shifted as a square of particular dimensions in order to approach a precise east-west orientation: however, the shift also means a consciously staged breaking away from fixed structures.

[Figure: A9]
All the figures standing next to each other in isolation now acquire a connecting access corridor in the interior. While the administrative buildings seem fixed as a copy of the grid structure, further distortion of the squares occurs in the corners of the enclosing square. The northern square is an extraordinarily large entrance hall with show staircases, and shifts outwards by the distance of the access figure, while the mosque building in the south forms four circles within the outline of the square that combine at the corners with a central square figure. The dramatic break away from the frame of the starting square occurs only in the north-south direction, thus supporting the oval's direction of movement from the center.

All the other figures distort within the frame and acquire independent - autonomous - form. Kahn chooses partial circular segments as forms in order to indicate the special function of these parts of the building: on the west side they are generous lounge areas for ministers and catering areas on the east side. However, the choice of the circle segments, as well as performing a functional task, clearly illustrates the distortion as a *crushing* and *compression* within the corset of the square framing. The exploded distance, the twisting of the central circular figure of the hall, is retained in the interior in both these figures by a central rectangular zone, but also in the realized facade image by a slit.

[Figure A10]

Thus, the figure of the parliament building is almost completely developed in its final shape. The isolated, central assembly chamber now acquires polygonal form because of the transfer of the segment already sketched in a north-south direction in previous steps to all axes. This provides access zones or sitting areas with various functions dependent on the particular level. The extended polygon emerges as the final external outline of the hall simply by combining these segments within the ground plan figure. A final circle in the center with half the radius of the hall indicated the central sitting area for the members of parliament.

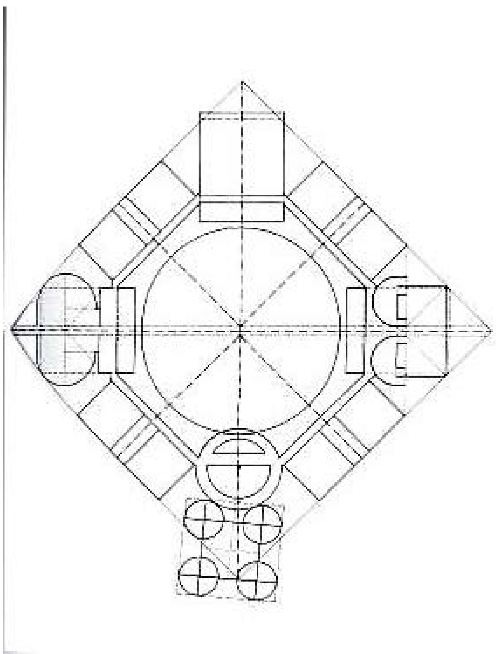


Figure: A9

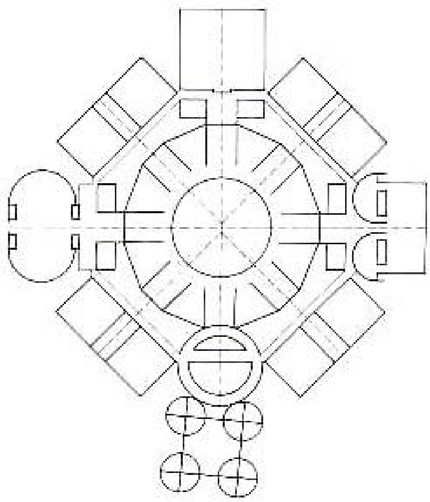


Figure: A10

Between the hall and the peripheral area is an airspace, a kind of covered exterior area, from whose access galleries the autonomous character and the dimension of the buildings can be grasped in full height. All the sections of the building remain distinguishable as single elements in the exterior, but they are bound together into a unit that forms a whole by the ordering structure of figurative geometry, which cannot be grasped directly but is always present.

The parliament building in Dhaka is Kahn's largest, but also his most extraordinary work. It can be called the culmination of several creative phases, and perhaps reflects in the most impressive way Kahn's concern to develop an all-embracing, culture-linking, indeed global architectural language intended to reach far into the 21st century. But only the future will show whether the degree of absoluteness envisaged by Kahn for an "expression of architecture", as he called it, deviating from the taste of its times, hurrying ahead of the misunderstandings current when it was created, committed to that time, but constantly valid, created by an "imperfect" human individual, whether all these things will have found appropriate form in this building as a complex, innovative work of architecture, and will finally do justice to its high demands, from which western categories are partially withdrawn.

APPENDIX B ½ BIBLIOGRAPHY AND REFERENCES

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[For a more comprehensive bibliography on shape grammars papers and writing, *see Shape Grammar website, also linked from Terry Knights web page* http://www.mit.edu/tknight/]