STRUCTURAL MORPHOLOGY AS A FIELD OF ARCHITECTURAL INQUIRY

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INTRODUCTION

Usually, one encounters the concept of structure arising in several different contexts in architecture. One of these is the use of the word for physical entities resulting from construction as, for example, in referring to a building or a structure. Disregarding this use as being significantly different than the concern of this paper, we can distinguish two further contexts in which usage is well established:

1. A physical construct as an assembly of material elements related to or studied from a mechanical point of view, e.g. the structure or the structural system of a building.

2. The interrelationship of any set of abstract or concrete elements that can be identified as forming a whole, e.g. social structure, or the whole itself, e.g. a spatial structure.

Not only are the vocabulary and operational concepts associated with these two contexts different, but the nature and the amount of academic attention they have received have been different as well.

Structure, in the first context, has been the subject of considerable attention as a field of inquiry in architecture and, particularly, structural engineering. The functional relationship and similar preoccupations of these professions has been, perhaps, a fundamental factor contributing to the use and wide acceptance of the terms structure in architecture and architectural structures as equivalent to this context. More noteworthy, however, is the amount of theoretical and experimental work in this field. This factor has served towards entrenching this context as a fundamental part of the architectural curriculum even though there persists a constant discontent with the nature of instruction in this field.

In contrast, there have been no studies in architecture of structure in the second context until very recently, apart from studies of a speculative and descriptive character. In fact, "[this] concept of structure has been continually misrepresented in environmental studies obscuring by far the most profound, scientific and fertile of the foundational concepts of the sciences of organisation." An excellent evidence of this is the absence of a unified formal study of structure in the architectural curriculum. This is all the more surprising when one considers that the concepts of structure and form are inextricably bound together and that
the latter forms a central concern of architecture. Even in the study of form, architecture is not strikingly outstanding for having accumulated and compiled knowledge into an operational quantitative theory. "This of course is a double bind: the science of form is not developed and supported (as a worthy academic discipline) because the science of form is not developed enough to be supported.""}

However, "the increasing concern of twentieth century science for questions of form, structure, morphology and organisation" has not left architecture untouched. There has been a significant growth in the study of form and structure (in the second context) so that it is now possible to identify and to argue for a fundamental discipline in architectural inquiry in both its educational and research aspects.

This "fully-fledged science of architectural morphology (identified) as a central discipline in architecture, the science of architecture as a whole" constitutes the subject matter of this paper. The main argument that will be put forward is that a very fruitful approach may be made to this field through structural morphology. To serve as a foundation for such an argument, the concepts of form and structure are examined and defined from a structural viewpoint. Several examples, taken from apparently different fields of study, are used to illustrate the essential characteristics of the discipline.

**STRUCTURE AND FORM**

Architecture, in its aspects as an academic discipline, is concerned with understanding the relationships that exist in natural and artificial wholes and, as a vocation, is concerned with generating relationships in the form of spatial constructs. In both instances, relationships in the concrete, such as a structure of building components, as well as relationships in the abstract, such as a structure of activities, are involved.

The most fruitful approach that can be made towards the study of such a wide variety of relationships is through the concept of structure in mathematics.

If [mathematical languages] are useful for representing the most abstract forms of order in the real world, it is because, in its preoccupation with its own structure, mathematics arrives at general principles of structure, which, because they are deep and general, hold at some level in the real world.

Proceeding with this idea, we may define structure as a set of elements together with one or more relations and/or operations defined on it. This is precisely the definition of mathematical structure and to give it an architectural content entails, of course, identifying the nature of the elements and demonstrating the architectural relevance of the relations and/or operations involved. Both of the two contexts discussed at the outset are covered by this definition, thus resolving the problem of conceptual difference.

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6. More strongly voiced and accusing in tone is the observation that "l'évolution du manque d'idées en architecture et urbanisme des cinquante dernières années... se trouve dans... l'absence totale de connaissances morphologiques qui permettraient de mettre en correspondance les phénomènes aux organisations spéciales adéquates." D.G. EMMERICH, Morphologie et structure, L'architecture d'aujourd'hui, n. 160, 1972, p. 21.


9. The concepts of relation and operation must be understood in their mathematical context. See, for example, M.GOWAR and H.C.FLEGG, Basic Mathematical Structures, 2 vols., London: Transworld Publishers Ltd., 1974, p. 241. As an operation is a special type of relation, the following definition has been given: "A structure is a set of any elements between which, or between subsets of which, relations are defined." M.LANE, Structure and structuralism, "Introduction: A reader" London: Jonathan Cape, 1970, p. 24.
With such a definition, we may distinguish between relational structures, (i.e. those consisting of a set of elements together with a relation) and operational structures, (i.e. those defined by operations.) It appears that this distinction is also a functional one; the former type usually arises in understanding structures that already exist in wholes whereas the latter arises in problems related to the structural generation of wholes. Very crudely, these correspond to analysis and certain stages of design, respectively.

Probably the most significant development in the study of relational structures in architecture has been the introduction of a simplicial complex by Atkin. A simplicial complex consists of a relation between a well-defined finite set and a subset of its power set, i.e. a set of its simplices. Each simplex is a collection of several of the elements of the finite set and whenever a particular simplex is contained in the simplicial complex, its sub-simplices, i.e. simplices of lesser order, are contained as well. In a simplicial complex, the relation is in the nature of a partial ordering on the simplices so that the structure is an order structure.

Such a structure is established whenever a relation can be set up between two finite sets. As one can easily think of well-defined sets of different things with relations between them in the architectural realm, this fact immediately makes obvious the applicability of such structures in architecture. But, in addition, there are two further significant aspects of the proposal of a simplicial complex. The first of these is the extent of the possibility offered by a mathematically based language.

A simplicial complex has a representation as a geometric structure in multidimensional space and this can be used in examining the global properties of the structure. It also has another representation (as an extended exterior algebra) which may be used in studying local characteristics. Concepts such as connectivity, pattern and flow, which, previously, could only be understood intuitively, may be given precise meaning and can be handled quantitatively.

Secondly, the introduction of a simplicial complex as a model of structure permits a formalization of the concept of hierarchy, which transcends but includes notions of hierarchy as defined in tree structures and semi-lattices. This understanding of hierarchy has an implicit conception of form which is central to our discussion.

In a relational structure, form can be considered as an element at some hierarchical level such that the set of which it is an element forms a mathematical cover of the elements at a lower hierarchical level in the same structure. This is tantamount to interpreting form as structure such that "a component(form) at one level can be used as a convenient description of some portion at a lower level and whose structure we can agree temporarily to overlook." Operational structures in architecture, on the other hand, have arisen through experience with computer aided architectural design. Problems of representation of architectural forms in computer studies have led to the utilization of structures consisting, typically, of a set of spatial elements, i.e. subsets of two three dimensional Euclidean space, with operations of transformation and
composition defined on it. Such structures have a combinatorial character and any combination of elements resulting from them is viewed as a form.

Each of the elements is allowed a certain range of variation of type and dimension and by assembling combinations of variations on the elements, widely varied architectural forms are generated. In this sense, computer aided design, as it is currently approached, may be seen as a direct extension of the academic classical tradition of elementary composition and particular computer aided design systems as embodying particular theories of architectural form in much the same way as treatises of Serlio, Durand and Guadet.

By giving a definition of structure as above and interpreting form either as an hierarchical element in a relational structure or as a combinatorial assembly in an operational structure, both conceptions of form as structure, we are in effect, adopting a structuralist approach to morphology. This is of fundamental importance as far as methodology is concerned because a strong link to the methods of other fields of scientific study, which use structuralist approaches, is thereby established. Although content is different, this may form one of the foundations of architectural science.

One of the more important consequences of interpreting structures in the sense that we have been discussing is the potential of studying morphisms between structures. Two significant aspects of this potential may be considered:

Because architecture is concerned primarily with spatial structures and their relation to other phenomena, the idea of a morphism is central to architectural inquiry. "The mutual interaction of a spatial with an aspatial structure is itself a structure describable in a higher dimensional mathematical space" and this presents a fundamental structural basis for the study of such problems.

Secondly, the possibility of utilizing the same methods in problems of structures arises as a fundamental technique. Of course, such a technique presumes that isomorphisms have been shown to exist between structures of different constitution. The advances to be made through such analogies of methodology are self-evident.

**STRUCTURAL MORPHOLOGY**

Just as it is of paramount importance to an understanding of the natural and social environment, the study of forms and structures constitutes a basic tool not only for the proper understanding of the man-made environment but also of its design.

A designer with a well understood and structured vocabulary of form is more likely to find suitable matchings with functional requirements than one who attempts to let form follow function in some supposedly self-generative way.

The advantages of the union of conceptually and materially different contexts into a formalized core through the establishment of a guiding line of thought, thus make imperative
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In addition to theoretical methods, it is conceivable that descriptive structural morphology will benefit greatly from experimental approaches in the geosciences, biosciences and metallurgy. The applications of terrestrial and aerial photogrammetry in architecture and urban studies is well advanced in practice as, probably, extensions from stereology, stereoscopy and hologrammetry will soon be in research.

Similarly less effort has been directed towards descriptive problems of aspatial structures. In fact, the only examples that can be quoted in an architectural context are studies on the structure of architectural design and evaluation processes and visual structure. Relevant studies are found, however, in other fields with emphasis given to symmetry, hierarchy, stability and structural change.

The main objective of analytic structural morphology is the study of the interrelationship of various structures. In the architectural context, this usually means the relation of spatial and/or material structures to other phenomena. If the existence of a deterministic relation is considered acceptable, an alternate way of stating this would be the relation of spatial/material structures to their determinants.

These determinant phenomena are diverse in character varying from physical ones like mechanical phenomena to physiological or psychological ones. Indeed, the objective given above covers an extremely wide range of problems, a large part of which falls within the domain of building science.

Structural analysis, as used in its engineering sense in the first context discussed at the outset of this paper, constitutes one of the most advanced areas of analytic morphology. Conceived with the relationship between material structures and force systems, the field itself is probably the oldest scientifically based discipline in engineering. In spite of this, structuralist approaches in it are fairly recent and have developed in parallel with demands placed by computerized analysis. Based on topology, graph theory and projective geometry, such studies now constitute a branch of structural analysis known as structural topology.

A similar instance of recent structuralist approaches in a related well-established field is to be found in the study of kinematic problems of rigid body structures.

Relations of spatial structures to activity, communication and circulation structures form another predominant subject of analytic structural morphology. These are some of the first problems to be investigated in computer aided architectural design and have received increasing attention since. The influence of computers is also apparent in problems of representation of spatial structures with particular reference to data structures and algorithmic structures.

More in parallel with studies in building science are problems related to light, including scigraphic aspects of spatial structures and luminous interaction of structures of reflective planes. Other obvious candidates are the relations of spatial/material structures to aerodynamic, acoustical and thermal phenomena. The simultaneous treatment of two or more phenomena does not appear to have attracted much attention at the present time.
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In contrast to descriptive structural morphology, analysis relies very heavily on experimentation in addition to theoretical methods. These are generally based on the theory of models to a large extent because of the greater size and cost of prototype material structures involved in architecture. Although not an integral part of it, dimensional analysis thus constitutes a basic tool in analysis structural morphology.

A fundamental concern of analytic structural morphology should be the investigation of the existence of common concepts and processes in contextually different studies. Such an attempt at unification would rely on a basic study of morphisms and would aid greatly in understanding and establishing the fundamental laws of structure, regardless of the content of the specific structures involved.

Apart from the obvious differentiation between synthesis of spatial/material versus aspatial structures, a fundamental distinction may be made in synthetic problems according to whether synthesis is approached on the basis of spatial factors or on the basis of other phenomena. From a slightly narrower viewpoint, we may differentiate, in other words, syntheses approached through descriptive factors and through analytic factors.

In the former category, we may note recent work on shape grammars, which are structures for the generation of shapes and are used extensively in artificial perception, studies on metric optimization in rectangular dissections in the plane and certain studies related to the synthesis of curves. These are only indicative of the diverse nature of the synthetic problems involved.

Structural design in the engineering sense represents an excellent example of the class of synthetic problems as approached through analytic criteria. The objective here is the design of a material structure on the basis of mechanical criteria, in parallel with the trends of structural analysis, structural design has only recently proceeded from optimization on the geometric dimensions of specific structures to the topological synthesis of the structure. However, "much more work remains to be done [on the geometry] and on [the topology of the structure] where significant practical literature is almost non-existent,"

On the other hand, examples of even a comparable degree of refinement cannot be quoted as regards approaches to structural synthesis on the basis of other phenomena, such as acausal, thermal, visual or psychological ones. At this time, only spatial synthesis, which approaches the problem through questions of activity and circulation planning, presents an advanced stage of synthesis.

To attempt to study synthetic structural morphology with a view towards unification of methodology appears to be a very difficult, if not insurmountable, task. There are, nevertheless,
several studies towards a science of design\textsuperscript{59}, with which synthetic structural morphology would exhibit mutual involvement.

A CENTRAL THEME

Concepts and problems of structure—and form viewed as structure—continually arise in different contexts throughout a wide spectrum in architecture. The same diversity also appears in the structuralist approaches to the fundamental issues of architecture and persists in architectural studies and education.

Historically and contextually different approaches to architectural problems may, indeed, have led to this diversity. But, as has been the main attempt of this paper, such diverse aspects can be shown to constitute special instances of a central concept of structure. Being so intimately concerned with the interrelationship of numerous elements, architecture must develop a central theory of structure which can be applied to its various aspects. Such a theory would constitute the field of structural morphology, comprising descriptive, analytic and synthetic aspects.

From a pedagogical standpoint, structural morphology may be interpreted to form a backbone of architectural education. Being rooted in mathematical structures (developing into applicable topics of calculus, linear algebra, graph theory, etc.) study may grow simultaneously into descriptive and projective geometry (incorporating manual and computer graphic representation of spatial structures.) Later, based on this foundation, different aspects such as vision, sciagraphy, structural mechanics, circulation and activity analysis, etc. may be treated, considering analytic and synthetic aspects simultaneously and progressively.\textsuperscript{59}

In research, it is becoming increasingly apparent that architectural design is, in fact, a special kind of problem solving process.\textsuperscript{60} Future directions of research in design thus lie in artificial intelligence where structural morphology will undeniably be of central importance in the development of data structures for representation, of operational structures for the generation of solutions and evaluatory structures for testing.

In light of the demands placed by developments in artificial intelligence on all design disciplines and the appearance of relevant studies in architectural research, it seems timely to forecast the adoption of structural morphology as a central theme of architectural inquiry, in both education and research.

MİMARLIKTA İNCELEME ALANI OLARAK YAPISAL ŞEKİL'BİLİM

ÖZET

Strüktür (yapı) kavramı mimarlık çeşitli şekillerde ortaya çıkmakta ve çoğu zaman taşıyıcı sistem karşılığında kullanılmaktadır. Bu kullanımı da içerecek biçimde, soyt analytic...
ile yapıyı inceleyebilenin en uygun yolu soruna matematiksel
yapı kavramı ile yaklaşılmaktır.
Böyle bir tanıma göre, ilişkiler ile belirlenen yapı kavramı,
ileğinler ile belirlenen yapı kavramından ayrıt edilebilir. Her
iki tür yapı, yakın zamanlarda mimarlık araştırmalarına
kullanılmaya başlanmıştır. Bu yaklaşım ile şekil de yapısal
bir şekilde görülebilen yapıların özel bir görünüşü şeklinde
ele alınabilir.
Yapı ve Şekil ile ilgili sorunların mimarlıkta ortak bir
şehirde incelemesi zorunludur. Yapısal şekilbilimin bu gibi
ortak bir yaklaşıma olanak sağlamaktadır.
Yapısal şekilbilimin betimsel, çözümsel ve bileşimsel yönlerini
ayrı ayrı etmek mümkündür. Mimarlıkta son yıllarda her üç yünde de
araştırmalar yürütülmekte, ancak bunların arasında bir bağ
bilmememektedir.
Mimarlık eğitimi ve araştırmasında yapısal şekilbilimin temel
bir tema olarak ele alınması, padagojik yönünden bir belkişimi
rolünü oynamabilir. Yapısal yaklaşımın birçok alanda
olduğu gibi mimarlık araştırmasında da görülemeye başlaması,
yapısal şekilbilimin mimarlıkta temel bir konu olarak
gelişebilme izlenimini desteklemektedir.

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