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STRUCTURAL MORPHOLOGY AS A FIELD OF ARCHITECTURAL INQUIRY[1]

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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.[2] 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."[3] An excellent evidence of this is the absence of a unified formal study of structure in the architectural curriculum. This is all the more surpising when one considers that the concepts of structure and form are inextricably bound together[4] and that

1. This paper is an extended and revised version of a presentation by the author to a seminar on graduate education in architecture and architectural sciences held at Karadeniz Technical University, Trabzon on June 15-17, 1976. See M.PULTAR, Mimarlık strüktürleri, *KTÜ Mimarlık Bülteni,* n.2, 1977, p.40-42

2. Evidence of this fact is to be found in the titles of two widely used *textbooks: M.SALVADORI* and *R.HEFFER, Structure in Architecture: Building of Buildings,*2nd ed, Englewood Cliffs: Prentice Hall, 1975. H.J.COWAN, *Architectural Structures: An Introduction to Structural Mechanics,* 2nd ed. Amsterdam: Elsevier, 1976.

3. B.HILLIER and A.LEAMAN, Structure, system, transformation: sciences of organisation and sciences of the artificial, *Transactions of the Bartlett Society*,v.9,1973,p.38.

4. The *usage of the concept of structure* in the context disregarded at the outset can, in fact, be ascribed to this equivalence of form and structure. For an example of synonymous and *interchangeable use in this context, see* F.MAKI an M.OHTAKA, Some thoughts on collective form, *Structure in Art and in Science,* ed. G.Kepes, London: Studio Vista, 1965, pp.116-127.

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."[5]

However, "the increasing concern of twentieth century science for questions of form, strucure, morphology and organisation"[6] 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 *architectonics*, the science of architecture as a whole"[7] 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.

5. L.MARCH and R.MATELA, The animals of architecture: some census results on N-omino populations for N=6,7,8, *Environment and Planning B*, v.1, n.2, 1974, p.212. More strongly voiced and accusing in tone is the observation that "l'évolution du manque d'idées en architecture et urbanisme des cinquante derniéres années .. se trouve dans .. l'absence totale de connaissances morphologiques, qui permettraient de faire correspondre les phénomènes aux organisations spatiales adéquates." D.G.EMMERICH, Morphologie et structure, *L'architecture d'aujourd'hui*, n.160, 1972, p.21.

6. B.HILLIER and A.LEAMAN, Structure, system, tranformation: sciences of organisation and sciences of the artificial, *Transactions of the Bartlett Society*, v.9, 1973, p.39.

7. L.MARCH and R.MATELA, The animals of architecture: some census results on N-omino populations for N=6,7,8, *Environment and Planning B*, v.1, n.2, 1974, p.213.

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.[8]

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.[9] 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.

8. B.HILLIER *et al.* Space syntax, *Environment and Planning B*, v.3, n.2, 1976, p.151.

9. The concepts of relation and operation must be understood in their mathematical context. See, for example, N.GOWAR and H.C.FLEGG, *Basic Mathematical Structures*, 2 vols., London: Transworld Publishers Ltd., 1974. As an operation is a special type of relation, the following definition has also 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, *Structuralism: 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.[10] 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.[11] 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."[12]

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

10. R.H.ATKIN, Urban Structure Research Report I, University of Essex, *Colchester, Essex,* 1972. *The application* of this concept of structure in architecture has been discussed in R.H.ATKIN, An approach to structure in architectural *and* urban design, *in* 3 parts, *Environment and Planning B*, Part 1: Introduction and mathematical theory, v.1, n.1, 1974, pp.51-67; Part 2: Algebraic representation and local structure, v.1, n.2, 1974, pp.173-191; Part 3: Illustrative examples, v.2, n.1, 1975, pp.21-57. Application to other problems is discussed in R.H.ATKIN, *Mathematical Structure in Human Affairs*, London: Heinemann Educational, 1974.

11. The concept of hierarchy as defined in a tree structure is formalized in M.BUNGE, The metaphysics, epistemology and methodology of levels, *Hierarchical Structures*, eds. L.L.Whyte et *al.* New York: American Elsevier Publishing Co., 1969. The classical discussion of hierarchy in a semilattice in the urban context is given by C.ALEXANDER, A city is not a tree, in 2 parts, *Architectural Forum*, Part 1: v.122, n.1, 1965, pp.58-62; *Part 2: v.122, n.2, 1965, pp.* 58-61. Also in *Design*, n.206, 1966, pp.46-55.

12. "Componeqc" *in* this quotation is precisely the concept of form which is implied in this paper. R.H.ATKIN, An approach to structure in architectural *and urban design 1: Introduction and* mathematical theory, *Environment and Planning B*, v.1, n.1, 1974, p.54.

composition defined on it.[13] 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.[14]

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,[15] we are in affect, 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.[16] 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[17] between structures. Two singnificant 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"[18] 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.[19]

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.[20]

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

13. A representative example is given in C.EASTMAN, An interrogation language for building descriptions, *Models and Systems in Architecture and Building*, ed. D.Hawkes, Hornby, Lancaster: The Construction Press Ltd., 1975, pp. 134-145.

14. W.MITCHELL, Vitruvius Computatus, *Models and Systems in Architecture and Building*, ed. D.Hawkes, Hornby, Lancaster: The Construction Press Ltd., 1975, p.55.

15. Reporting on the developments in concepts of form, Whyte had observed that "the unifying natural philosophy of the coming period may be a morphology: a doctrine of form viewed as structure." L.L.WHYTE, Atomism, structure and form: a report on the natural philosophy of form, *Structure in Art and in Science*, ed. G.Kepes, London: Studio Vista, 1965, p.20.

16. The principles of structuralism as a common method of approach in the sciences is examined by J.PIAGET, *Structuralism*, trans. C.Maschler, London: Routledge and Kegan Paul, 1971(1968) Also noteworthy, as an excellent introduction, is M.LANE (ed.) *Structuralism: A Reader*, London: Jonathan Cape, 1970.

17. A morphism is a relation between two mathematical structures such that one may be said to model the other. Of special interest is an isomorphism in which there is a one-to-one correspondence of the constituent parts of the involved structures.

18. R.H.ATKIN, An approach to structure in architectural and urban design 1: Introduction and mathematical theory, *Environment and Planning B*, v.1, 1974, p.53.

19. This is a well established method in the natural and applied sciences. See E.TONTI, The reason for analogies between physical theories, *Applied Mathematical Modelling*, v.1, n.1, 1976, pp. 37-50.

20. L.MARCH and R.MATELA, The animals of architecture: some census results on N-omino populations for N = 6,7,8, *Environment and Planning B*, v.1, n.2, 1974, p.212.

the adoption of the study of form and structure in architecture as a well-defined and unique field of study.

It is very natural to call this field of study *structural morphology* not only because it is the study of structure and form, but also because structuralism lies at its core. According to the ultimate objective and the direction of specific problems undertaken, we may distinquish the descriptive, *analytic and synthetic aspects of structural morphology.*

Descriptive structural morphology has two main objectives:

1. The identification of structures in architecture; namely, the definition of the elements, relations and operations involved, and the study of methods applicable to their description.
2. The study of structural characteristics, such as stability, connectivity, hierarchy, change, growth and transformation, of architectural structures.

It is reasonable to expect that spatial structures and material structures (i.e. those spatial structures whose elements are differentiated by the materials of their construction) will form a major subject matter of structural morphology. Indeed, it is very difficult to conceive of an aspatial architectural form. As an indication of this, descriptive studies in structural morphology have been concentrated mainly on spatial structures.

Classical methods of geometry such as analytic (coordinate) geometry, differential geometry and descriptive geometry have been applied to the study of spatial structures for a very long time.[21] Yet, it is justified to describe the topic as "the most indeterminate subject of all - that of shape or form and its quantitative description."[22] One reason for this may lie in the fact that these approaches are concerned with metric but not structural properties.

Recent studies in description, however, have taken the form of investigations through the concepts of set and group theories,[23] graph theory[24] and Boolean algebra.[25] Especially demands placed by the requirements of data structures in computer representation have led to a rigorous study of the descriptive problems of spatial structures in fields as diverse - but not unrelated - as computer-aided geometric design[26], architecture[27], structural engineering[28], pattern recognition[29] and of spatio-temporal structures in regional planning[30]. As a direct outcome of this, a new field known as computational geometry has made significant advances, especially in the study of elemental (componental), translational and combinatorial complexity of spatial forms.[31]

As an extension of structuralist approaches in linguistics, one of the most interesting recent trends of descriptive structural morphology is in the direction of studies on syntactic *structures of spatial forms and their relation to settlement* patterns.[32] Also in this class may be quoted work on shape grammars which are examined later in their synthetic aspect.

A large class of descriptive problems is related to projective *isomorphisms and problems which may be linked to questions of* vision. The basis of this work is in projective and transformational geometry.[33] Advancing in parallel with computer graphics, several aspects of these developments are operational in computer aided architectural design.[34]

21. Recent comprehensive treatments of these topics include M. DO CARMO, *Differential Geometry of Curves and Surfaces,* Englewood Cliffs: Prentice Hall Inc., 1976; M.H.PROTTER and C.B.MORREY, *Analytic Geometry,* Reading, Mass.: Addison-Wesley, 1975; H.J.EARLE, *Descriptive Geometry,* Reading, Mass.: Addison-Wesley, 1971.

22. E.UNDERWOOD, *Quantitative Stereology,* Reading, Mass.: Addison-Wesley, 1970, p.195.

23. L.MARCH and P.STEADMAN, *The Geometry of Environment,* London: RIBA Publications Ltd., 1971.

24. For a comprehensive survey on graph-theoretic approaches, including rectangular dissections, see P.STEADMAN, Graph-theoretic representation of architectural arrangement, *The Architecture of Form,* ed. L.March, London: Cambridge University Press, 1976, pp. 94-115. See also R.MATELA and E.O'HARE, Graph-theoretic aspects of polyominoes and related spatial structures, *Environment and Planning B,* v.3, n.2, 1976, pp. 79-110.

25. L.MARCH, A Boolean description of a class of built forms, *The Architecture of Form,* ed. L.March, London: Cambridge University Press, 1976, pp. 41-73

26. R.E.BARNHILL and R.F.RIESENFELD (eds.), *Computer Aided Geometric Design,* New York: Academic Press, 1974.

27. D.HAWKES and R.STIBBS, Computer description of built forms, *The Architecture of Form,* ed. L.March, London: Cambridge University Press, 1976 pp. 116-158.

28. H.NOOSHIN, Algebraic representation and processing of structural configurations, *Computers and Structures,* v.5, 1975, pp. 119-130.

29. S.WATANABE, Ungrammatical grammar in pattern recognition, *Pattern Recognition,* v.3, 1971, pp. 385-408.

30. A.D.CLIFF et al., *Elements of Spatial Structure,* London: Cambridge University Press, 1975.

31. A.R.FORREST, Computational geometry-achievements and problems, *Computer Aided Geometric Design,* eds. R.E.Barnhill and R.F.Riesenfeld, New York: Academic Press, 1974.

32. B.HILLIER et al., Space syntax, *Environment and Planning B,* v.3, n.2, 1976, pp. 147-185. For the basic structuralist approach involved see N.CHOMSKY, *Syntactic Structures,* The Hague: Mouton, 1972.

33. For mathematical principles see E.A.MAXWELL, *Geometry by Transformations,* London: Cambridge University Press, 1976 and H.S.COXETER, *Projective Geometry,* Toronto: University of Toronto Press, 1974. Computer applications are discussed in D.F.ROGERS and J.A.ADAMS, *Mathematical Elements for Computer Graphics,* New York: McGraw Hill Book Co., 1976 and architectural applications in R.FORREST, Transformations and matrices in modern descriptive geometry, *The Architecture of Form,* ed.L. March, London: Cambridge University Press, 1976, pp. 159-184.

34. Among numerous others, see H.SUSSOCK, Computer generated perspective views, *ABACUS Occasional Paper,* n.32, University of Strathclyde, Glasgow, 1974 and İ.CANBULAT and M.PULTAR, An algorithm for plotting computerized hidden-line perspectives, *METU Journal of the Faculty of Architecture,* v.2, n.2, 1976, pp. 233-246.

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[35] as, probably, extensions from stereology, stereoscopy and hologrammetry will soon be in research.[36]

Considerably 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[37] and visual structure.[38] Relevant studies are found, however, in other fields with emphasis given to symmetry[39], hierarchy[40], stability and structural change.[41]

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. Concerned 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.[42] Based on topology, graph theory and projective geometry, such studies now constitute a branch of structural analysis known as structural topology.[43]

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.[44]

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.[45] The influence of computers is also appearent in problems of representation of spatial structures with particular reference to data structures and algorithmic structures.[46]

More in parallel with studies in building science are problems related to light, including sciagrahic aspects of spatial structures[47] and luminous interaction of structures of reflective planes.[48] Other obvious candidates are the relations of spatial/material structures to aerodynamic[49], acoustical and thermal phenomena. The simultaneous treatment of two or more phenomena does not appear to hava attracted much attention at the present time.

35. R.A.DALLAS, *Architectural Photogrammetry*, London: Commonwealth Association of Architects, 1975.

36. Stereology is concerned with the study of three dimensional spatial structures as approached through two dimensional sections, stereoscopy through biaxial views and hologrammetry through the use of holography. See E.UNDERWOOD, *Quantitative Stereology*, Reading. Mass.: Addison-Wesley, 1970; N.A.VAYLUS, *Stereoscopy*, trans. H.Asher, London: Focal Press, 1966; E.M.MIKHAIL, Hologrammetry: concepts and applications, *Photogrammetric Engineering*, v.40, n.12, 1974, pp. 1407-1422.

37. Best known in this context is C.ALEXANDER, *Notes on the Synthesis of Form*, Cambridge, Mass.: Harvard University Press, 1964. See also A.TZONTIS and O.SALAMA, Problems of judgement in programmatic analysis in architecture: the synthesis of partial evaluations, *Journal of Architectural Research*, v.4, n.4, 1975, pp.47-54.

38. R.H. ATKIN, *Mathematical Structure in Human Affairs*, London: Heinemann Educational Books Ltd., 1974.

39. The classical work on symmetry is A.V.SHUBNIKOV and V.A.KOPTSIK, *Symmetry in Science and Art*, trans. G.D.Archard, New York: Plenum Press, 1974. See also H.WEYL, *Symmetry*, Princeton: Princeton University Press, 1952.

40. M.D.MESAROVIC and D.MACKO, Foundations for a scientific theory of hierarchical systems, *Hierarchical Structures*, eds. L.L.Whyte *et al*., New York: American Elsevier, 1969.

41. R. THOM, *Structural Stability and Morphogenesis: An Outline of a General Theory of Models*, trans. D.H.Fowler, Reading, Mass.: W.A.Benjamin, Inc., 1975(1972)

42. A concise presentation is given in W.R.SPILLERS, *Automated Structural Analysis: An Introduction*, New York: Pergamon Press, 1972.

43. The term was coined in 1974 by J.J.BARACS, Rigidity of articulated spatial panel structures, *Bulletin of the International Association for Shell and Spatial Structures*, v.16, n.3, 1975, pp. 37-52. also in *Preliminary Publication*, IASS-CISM Symposium on Folded Plates and Spatial Panel Structures, Udine, Italy: Centre International des Sciences Mécaniques, 1974, (no pagination)

44. F.FREUDENSTEIN and L.S.WOO, Kinematic structure of mechanisms, *Basic Questions of Design Theory*, ed. W.R.Spillers, Amsterdam: North Holland Publishing Co., 1974, pp. 241-264.

45. A critical review is given in P.TABOR, Analysing communication patterns, and P.TABOR, Analysing route patterns, both in *The Architecture of Form*, ed. L.March, London: Cambridge University Press, 1976, pp. 284-351 and pp. 352-378, respectively. See also T.M.WILLOUGHBY, Building forms and circulation patterns, *Environment and Planning B*, v.2, n.1, 1975, pp. 59-87.

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 great 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 analytic 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.

Being concerned with the determination of structures and forms to suit particular objectives, *synthetic structural morphology* is, in a sense, the main activity of architecture[50] or of any other design discipline. It would be very pretentious to attempt discussing and reviewing such a wide field from the narrow structuring angle of this paper. Nevertheless, one point deserves comment as a natural extension of the arguments presented previously.

Apart from the obvious differentiation between synthesis of spatial/material versus aspatial[51] 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[52], 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[53] and certain studies related to the synthesis of curves.[54] These are only indicative of the diverse nature of the synhetic 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[55] 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."[56]

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 acoustical, 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.[57]

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,

46. Problems related to data structures are discussed by J.TOMLINSON, Computer representations of architectural problems, *Models and Systems in Architecture and Building*, ed. D.Hawkes, Hornby, Lancaster: The Construction Press Ltd., 1975, pp. 60-69. Problems related to algorithmic structures are discussed in A.A.KAPOSI, An engineer's guide to algorithmic structures, *Computer Aided Design*, v.9, n.1, 1977, pp. 58-65.

47. A program on sciagraphic resolution which is operational in a computer aided *architectural design system is described* by J.A.CLARKE, External shading of buildings, *ABACUS Occasional Paper*, n.49, University of Strathclyde, Glasgow, 1976.

48. R. STIBBS, Prediction of surface luminances in architectural space, *The Architecture of Form*, ed. L.March, London: Cambridge University Press, 1976, pp. 239-249.

49. R.M.AYNSLEY *et al.*, *Architectural Aerodynamics*, Essex: Applied Science Publishers, 1977.

50. It is interesting to note that in its age-old tradition of adopting fashions in parallel with contemporary *scientific thought, architectural design* is developing a new "structuralist" trend. A.LUNCHINGER, Strukturalismus-eine neue Strömung in der Architektur, *Bauen und Wohnen*, v. 31, n.1, 1976, pp. 5-9.

51. An interesting example of aspatial structural synthesis on the basis of probabilistic performance measures is given in S.GOODMAN and D.SHIER, On designing a reliable hierarchical structure, *SIAM Journal of Applied Mathematics*, v.32, n.2, 1977, pp.418-430.

52. J.GIPS, *Shape Grammars and Their Uses*, Basel: Birkhauser Verlag, 1975; G.STINY, *Pictorial and Formal Aspects of Shape and Shape Grammars*, Basel: Birkhauser Verlag, 1975. G.STINY, Two exercises in formal composetion, *Environment and Planning B*, v.3, n.2, 1976, pp. 187-210.

53. W.J.MITCHELL et *al.*, Synthesis and optimization of small rectangular floor plans, *Environment and Planning B*, v.3, n.1, 1976, pp. 37-70.

54. T.K.PAL and A.W.NUTBOURNE, Two dimensional curve synthesis using linear curvature elements, *Computer Aided Design*, v.9, n.2, 1977, pp. 121-134.

55. A good review of the state of the art is given in W.R. SPILLERS, Some problems of structural design, *Basic Questions of Design Theory*, ed. W.R. Spillers, Amsterdam: North Holland Publishing Co., 1974, pp. 103-117.

56. A.B.TEMPLEMAN, Optimization concepts and techniques in structural design, *Introductory Report*, Tenth Congress of the International Association for Bridge and Structural Engineering, Zürich: Secretariat of the IABSE, 1975, p.44.

57. C.M.EASTMAN (ed.), *Spatial Synthesis in Computer Aided Building Design*, Essex: Applied Science Publishers, 1975.

several studies towards a science of design[58], with which synthetic structural morphology would exhibit mutual involvement.

58. For a discussion of the concept of a science of design, see H.A.SIMON, *The Sciences of the Artificial*, Cambridge, Mass.: MIT Press, 1969.

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.[59]

In research, it is becoming increasingly appearent that architectural design is, in fact, a special kind of problem solving process.[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.

59. In fact, the design of an architectural curriculum itself may be considered as a problem in structural synthesis. See G.HAIDER, Structures and architectural education-in search of directions, *Build International*, v.8, 1975, pp. 321-335.

60. W.J.MITCHELL, The theoretical foundation of computer aided architectural design, *Environment and Planning B*, v.2, n.2, 1975, pp. 127-150.

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 ŞEKİLBİLİM

ÖZET

Strüktür (yapı) kavramı mimarlıkta çeşitli şekillerde ortaya çıkmakta ve çoğu zaman taşıyıcı sistem karşılığında kullanılmaktadır. Bu kullanışı da içerecek biçimde, soyut anlamı

ile yapıyı inceleyebilmenin en uygun yolu soruna matematiksel yapı kavramı ile yaklaşmaktır.

Böyle bir tanıma göre, ilişkiler ile belirlenen yapı kavramı, işlemler ile belirlenen yapı kavramından ayırt edilebilir. Her iki tür yapı, yakın zamanlarda mimarlık araştırmalarında kullanılmaya başlanmıştır. Bu yaklaşım ile şekil de yapısal bir şekilde yorumlanarak yapının özel bir görüntüsü şeklinde ele alınabilir.

Yapı ve Şekil ile ilgili sorunların mimarlıkta ortak bir şekilde incelenmesi zorunludur. Yapısal şekilbilim bu gibi ortak bir yaklaşıma olanak sağlamaktadır.

Yapısal şekilbilimin betimsel, çözümsel ve bileşimsel yönlerini ayırt etmek mümkündür. Mimarlıkta son yıllarda her üç yönde de araştırmalar yürütülmekte, ancak bunların arasında bir bağ bulunmamaktadır.

Mimarlık eğitimi ve araştırmasında yapısal şekilbilimin temel bir tema olarak ele alınması, padagojik yönden bir belkemiği rolünü oynıyabilir. Yapısalcı yaklaşımların birçok alanda olduğu gibi mimarlık araştırmasında da görülmeye başlaması, yapısal şekilbilimin mimarlıkta temel bir konu olarak gelişeceği izlenimini desteklemektedir.

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