An Attempt to Derive the Nature of a Human Building System from First Principles

Christopher Alexander

I wrote this paper for a seminar discussion in 1970. There is little in it which is precise enough to convince a person who is in a mood to doubt. However, for all that, I do believe that careful empirical study of the psychology of space, and the laws of efficient structure, will, in the long run show that my conclusions are fundamentally correct. For this reason, I am publishing them in this sketchy form with the idea that they may help some of my colleagues who are already looking in a similar direction.

When a person designs a building, he usually starts with certain known structure types: column and beam, load-bearing walls, stud construction, monolithic reinforced concrete, etc. The building forms which designers have created by this process are very unsatisfactory. To begin with, they fail to meet many important needs. What is far worse, though, these structure types are so sharply distinct, and the choices between them so arbitrary, that one is left with the feeling that none of them are really quite right, and that no one has ever plumbed the problem of defining the class of structures which are actually correct for a human building. For instance, comparison of columns-and-beams with load-bearing-walls, leaves you with the feeling that there

*The psychological arguments for Postulates 3, 6, 10, 11, 20 and 24 are given by the patterns Ceiling height variety, Indoor space, Columns at the corners, Thick walls, and Sheltering roof which will appear in the first edition of The Pattern Language, to be published in 1973. They are summarized, in part, in Alexander and Jacobson, Specifications for a Human Building System, this volume.

are certain pros and cons for each alternative, but that final choice among these alternatives is more or less arbitrary.

In this paper, I shall try to overcome this arbitrariness by arguing from first principles. I shall start with certain postulates, based on the human needs which occur in a building, and the laws of nature, and try to derive, from these postulates, a general description of the morphology--(i.e., the class of structure) which is correct for human buildings. As you will see, I believe we may conclude that any building structure which meets human needs, and follows the laws of structure, will have the general character of the room illustrated by the following drawing:

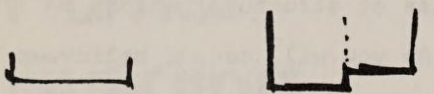
In order to derive the morphology of such a building without prejedice, it will be necessary to avoid assumptions about "types" of structure, like load-bearing-walls, shells, or column-and-beam--and instead carry on the discussion at a level of description which could apply equally well to any of these so-called types, and also to the very much greater variety of "mixed types" which lie between them. I begin with the most general description of a building:

Postulate 1.

From a human standpoint, a building may be viewed as a collection of indoor and outdoor spaces, each one defined by human or social purposes. If you think of each of these spaces as a solid lump, then you can visualize the building as a three dimensional arrangement of these lumps.

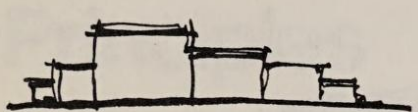
Postulate 2.

A Series of Postulates Concerning the Shape of the Lumps



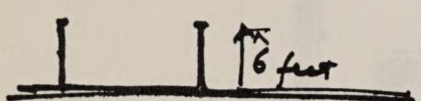
Each space has a horizontal floor. A change of floor level will be treated as a transition from one space to another.

Postulate 3.



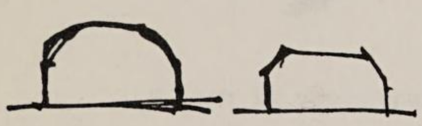
The ceiling heights of spaces vary according to their social functions. Roughly speaking, the ceiling heights vary with floor areas--large spaces have higher ceilings, small ones lower. (Ceiling height variety pattern)

Postulate 4.

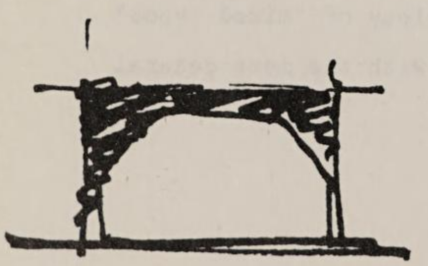


The edges of the space are essentially vertical up to head height--i.e., about 6 feet.

Postulate 5.

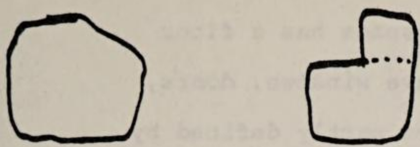


Above head height, the boundaries of the space come in towards the space. The upper corners between wall and ceiling of a normal room serve no function, and are wasted: it is therefore not useful to consider them an essential part of the space. This does not mean that the structure must have the configuration shown. It does mean that the most general shape for the space has this configuration, and needs no more, so a structure which enclosed more space would be wasteful.

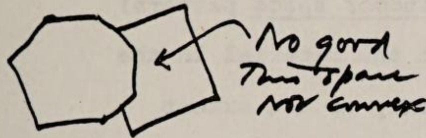


If another floor comes above, it needs to be like this, because the upper floor is flat.

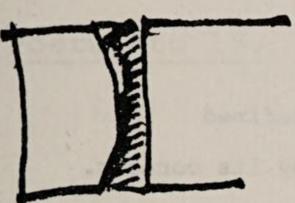
Postulate 6. Every space is convex in plan. This means that there are no re-entered angles in a space. Wherever such a re-entered angle does occur, it is considered to be the junction of two spaces. (Indoor space pattern)



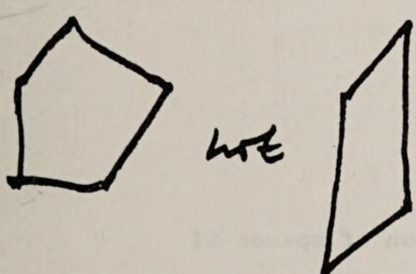
Postulate 7. The boundary of any space, seen in plan, is formed by segments which are essentially straight lines--though they need not be perfectly straight. The reason is this. A curved boundary makes a convex space on one side, but a concave space on the other--which is unacceptable, by postulate 6.



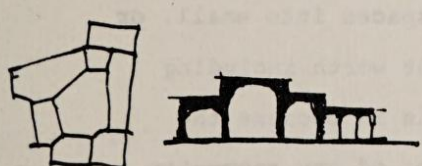
This means that every space is essentially a polygon in plan--though of course not necessarily rectangular. And if a space does have a boundary which is curved in plan, the wall must be thick enough for the next door space to have a straight boundary in plan.



Postulate 8. As a general rule, no space has any acute-angled corners. Acute angles are almost always useless: it is almost impossible to make an acute angle in a room, which works. Together with postulates 6 and 7, this means that the corners of the spaces are obtuse angles between 90 and 180 degrees.



Postulate 9. A building is a packing of polygonal spaces in which each polygon has a beehive cross section, and a height which raises according to its size. This follows from postulates 1 - 8.



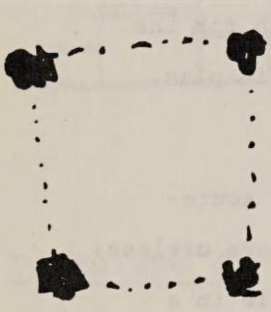
Postulate 10.

Postulates Concerning the Enclosure of Spaces

Within the building every space has a floor and a ceiling. It may or may not have windows, doors, partitions, etc. Each space must be partly defined by the material which forms its vertical boundary. However, it is by no means necessary for all this material to be there--a large part of it can be missing, and the space will still be defined and felt. (Indoor space pattern)

We assume, therefore, that the material in the boundary of a space need be there only to the extent that it is psychologically necessary to create the virtual space in people's minds.

Postulate 11.



A space with a polygonal plan is defined psychologically at least, almost entirely by its corners. There are exceptions, but as a general rule, this means there will need to be material in those parts of the boundary which form the corners of a space. (Columns at the corners pattern)

Postulate 12.

Postulates on Flexibility

The statistical distribution of spaces of different size (small, middle, large, etc.) is largely fixed by the nature of man and society--and does not need to change during the life of a building.

Attempts to change large spaces into small, or vice versa, always fail, and are not worth including in the concept of flexibility. This is because the three most important characteristics of any room--its height, acoustics, and natural light--are all critically related to room size, and will always be wrong after any change in which the size of spaces is itself changed.

From postulate 12 we may derive:

Postulate 13. The need for so-called flexibility in a building can be completely taken care of by changing the amount of enclosure round different spaces. There is never any sense in trying to change the basic spaces themselves.

Postulate 14. **Postulate on Design**

At some stage in the design process, it is possible to specify a building as a three dimensional arrangement of spaces, in which all the spaces have the characteristics defined above. This is the stage which immediately precedes the design of the load bearing structure.

Postulate 15. **Postulates on Structure**

To visualize the problem of defining the structure, in the most general sense, imagine the following process. Make a lump of wax, for each of the spaces which appears in the building, and construct a three dimensional array of these lumps of wax, leaving gaps between all adjacent lumps.

Now, take a generalized structure fluid, and pour it all over this arrangement of lumps, so that it completely covers the whole thing, and fills all the gaps. Let this fluid harden. Now dissolve out the wax lumps that represent spaces. The stuff which remains is the most generalized building structure.

This general structure is homogeneous. There are no distinctions, yet, between parts of it that work in compression, or in tension, and no distinction, yet, between columns, beams, arches, vaults, walls, etc.

Postulate 16. The problem of defining an ideal structure, is the problem of defining rules which will tell us how to take this homogeneous, ideal structure and make it into a real structure.

To make this imaginary ideal homogeneous "structure" into a real structure, three steps have to be taken.

a. We may move the original spaces around a little, in order to improve the global stability of the structure.

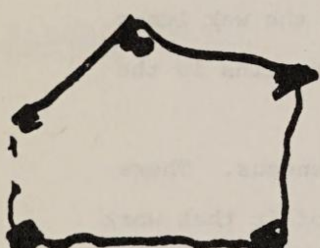
b. We have to define the positions of doors, windows and openings between spaces, and remove the material from the ideal structure, wherever these openings occur.

c. We have to define the distribution of thickness in the remaining ideal structure to optimize its resistance against actual loads--and specify the tension-compression characteristics of its different portions.

When these three steps are done, we shall have a complete, workable structure, with its geometry and thickness at every point specified in detail, and the compression and tension characteristics known at every point. At that stage, it will be possible to choose actual materials which have the geometry and stress characteristics of each piece within the whole.

Consider first the arrangement of spaces, in plan.

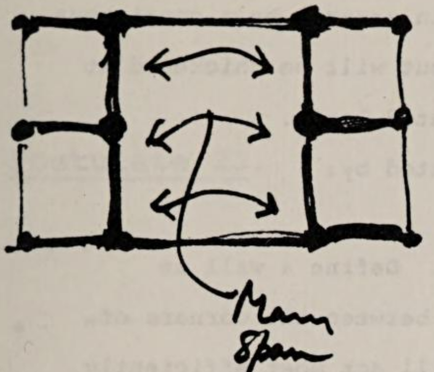
Postulate 17.



It is natural to expect that the corners of spaces, where the edges of different spaces meet, will have to carry the greatest load--since it is at these points that loads will change direction, and it is these parts of the vertical structure which will be subject to the greatest shear, bending and torsion. For this reason, it is natural to expect thickening at the corners. Although we need not think of the thickening as columns, it is congruent with the intuition already expressed in postulate 11, that a polygonal space is defined by its corners.

Postulate 18.

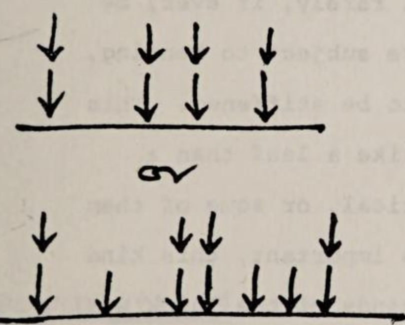
Each corner will either be a three or four way corner. This follows directly from postulate 8. A five way corner would create at least one acute angled space. If the connection is four way, it has to be right angled, to meet postulate 11. This means there are essentially three kinds of valid interior corners, in plan.



The T-junction is inherently less stable than the Y-junction, but makes sense if there is another horizontal load coming in from an arch, or other horizontal member, spanning the larger space.

Postulate 19.

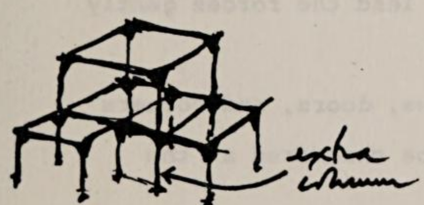
Vertical continuity. If the corners of spaces are most critical, and thickest, then these corners must be vertically continuous just as columns are in a conventional structure.



There are two ways of guaranteeing this.

Either a. Each corner, at a given level, must have corners below it at all lower levels. This is rather restrictive. It implies either that the floor plan at the second level is the same as that at the first, or that it is the same, with certain corners left out, which makes the spaces upstairs larger than those downstairs, and is unlikely to make sense in social terms, since larger spaces are usually more public, and need to be closer to the ground.

Or b. To get around this difficulty, we can say that the corners of spaces at the second floor, must at least fall above walls (i.e., boundaries between spaces), on the floor below, but not necessarily above columns.



This means that the lower walls will contain extra thickening at certain points which are not corners, to carry loads from upper floors, and the lowest floors will have the largest number of these extra "columns."

It is clear, therefore, that the wall between the corners of a space, will not in general be a continuous homogeneous non-loaded membrane, but will be thickened at certain points, to carry concentrated loads.

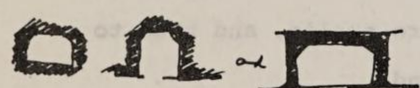
This principle is elaborated by:

Postulate 20.

Struts and ribs in walls. Define a wall as any part of the vertical boundary between the corners of a space. In general, this wall will act most efficiently if it is non-homogeneous, and braced and stiffened by thicker parts, which come out from its surface, at right angles to the surface.

There are several reasons. A homogeneous surface is never most efficient unless it is acting in pure tension. The walls of a space will rarely, if ever, be acting in pure tension. If they are subject to bending, compression, and shear, they need to be stiffened. This will need a wall which looks more like a leaf than a flat wall--the ribs may be all vertical, or some of them diagonal and horizontal. Even more important, this kind of wall is required to meet the demands of the Thick wall pattern.

Postulate 21.



Rounding corners. Right angled openings in a structure are the weak points in a structure, liable to cracking or rupture. All openings should, if possible, be rounded or angled off, so as to lead the forces gently round the opening.

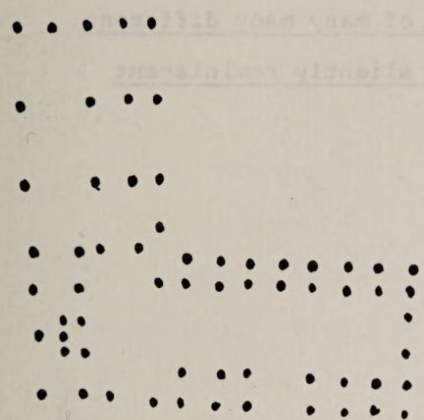
This means that all windows, doors, and corners between columns and beams, should be chamfered at the corners.

Postulate 22

Stiffening of all open edges. There are extra load concentrations at any free edge, so that all the openings round doors, windows, etc., must be stiffened by ribs or thickening, of the type already described under postulate 20. As a comment on existing ways of building, this suggests that window frame and door frames should play more of a part in the overall structure than they do today.

Postulate 23.

Horizontal continuity. In traditional column and beam structures, it is important to keep beams as long as possible, running through several columns, to reduce effective bending length. This is made possible, in part, by a grid of columns. However, it does not require a grid of equal spacing. It can be guaranteed, equally well, by a grid in which adjacent grid lines are unequally spaced: Thus, for example, this column grid allows perfectly adequate horizontal continuity in beam members.



Limited lining up of spaces of this kind will allow the beams to run continuously from one space to the next. Since, by postulate 5, the space for the beam is triangular in cross section, this will effectively create a system of intersecting triangulated barrel vaults.

Postulate 24.

Roof postulate. Floors need to be flat, and must therefore use a slightly inefficient structure, to create a flat upper surface. The roof does not need to be flat on top, except where there are roof gardens. For this reason, we should expect roofs to have the most efficient structural form - some type of dome or vault, either a single one, or a multitude of them covering individual spaces. This is perfectly consistent with postulate 5, which defines a similar shape for the inside of the spaces. In short, top storey spaces, will have their ceilings formed directly by the roof, which will be a sloping, dome or vaulted structure, except where there are roof gardens. This is also consistent with the psychological demands imposed by the Sheltering roof pattern.

Any building which satisfies these 24 postulates, will be made up of interior spaces which look more or less like this, but loosely packed, both horizontally and vertically, with some reasonable degree of continuity, but without being on any exact grid, either horizontally or vertically. As you can see, the structure is an archetypal one, and contains echos of many many different traditional building types. It is slightly reminiscent of a barn interior.

Christopher Alexander is the founder of the Center for Environmental Structure in Berkeley, California