The Determination of Components for an Indian Village

Christopher Alexander

INTRODUCTION

I. I shall discuss the general problem of finding the right physical components of a physical structure (or alternatively, the physical subsystems of a physical system).

II. This problem becomes especially urgent when we are faced with the development of a dynamic structure like a city; as I shall try to show, the nature of its components play a critical part in determining the rate and efficiency of its adaptation to new developments and changing situations.

III. The method I shall describe is based on non-numerical mathematics. It arises largely from the use of graphs (topological 1-complexes) to represent systems of interacting functions. Since the application of the method demands rather a lot of computation and manipulation, I have used the IBM 7090 computer to carry it out.

IV. For the sake of example I have chosen to work with a city in miniature, rather than a full-fledged city. During the last six months I have been working in an Indian village with a population of 600, trying to determine what its physical components should be, if its development and reactions to the future are to be efficient. I have some diagrams illustrating what I have done so far. In about a year's time I shall be going back to India to rebuild the village according to these principles.

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I. COMPONENTS

We sometimes forget how deeply the nature of an object is determined by the nature of its components. Once you decide that a car is to be made of four wheels, engine, chassis, and superstructure, there are really very few essential changes you can make. You can alter the shape of the components, and the way they are put together; but what you have remains a car, as we have known it now for fifty years, even though it may be this year's model rather than last year's. Or take an example from elementary chemistry. The difference between graphite and diamond is very largely caused by the difference in the structure of their component building blocks. Both are pure carbon; but in the case of diamond, where the carbon atoms are arranged to form tetrahedral components, the ensuing structure is hard and brilliant, while in the case of graphite, where the atoms are arranged to form flat plate-like components, the resulting substance is soft and black and slippery.

Now think of an example from architecture. If you ask anyone to name the pieces a city is made of, he will tell you that it is made of houses, streets, factories, offices and parks, and so on. This very obvious fact was formally recognized in the Athens charter of CIAM in 1929, which stated that the four functions of a city were work, dwelling, recreation, and transportation, and that the physical articulation of the city (that is, its breakdown into components) should follow this division of functions.

When we ask what it is that makes each one of these macro-components what it is, we see that, just as the component plates of graphite are themselves made up of carbon atoms, so each component of the city is really a collection of smaller elements, and that each gets its character from the way these smaller elements are grouped. A house is a collection of bricks and heaters and doors and so on, grouped in such a way, and with the divisions between groups, and the relations between different groups arranged in such a way that we call the thing a house. If the bricks are arranged differently we get a wall; if less homogeneously, we get a pile of rubble, or a path. It is not hard to see that these bricks and other pieces can be put together in millions of different ways, and that the macro-components might therefore be very different from those we are used to. There are, very likely, other, newer, macro-components, latent in the life of the modern city, which would serve better as the city's building blocks than the old ones do; but their growth is hindered by the persistance of the old roads and factories and dwellings, both on the ground, and in the designer's mind. The habit of mind which says that the city's component building blocks are houses, streets, parks and offices, is so strong that we take the components for granted: what we call design, consists of playing variations on the kinds of city you can get by arranging and rearranging these components. But this never leads to a new structure for the city. Whether the streets are curved or straight, or long or short, the houses large or small, the park in the middle of the city, or on the edge, the behaviour of the whole is fundamentally unchanged.

Not only are planners and designers often trapped by the persistance of the known components, but those systematic techniques under discussion at this conference often aggravate their fault. Statistical decision theory applied to transportation may tell you to put a road here rather than there. Linear programming applied to the distribution of apartments, family dwellings, or an office block, might give you an optimum distribution for them. Location theory might tell you where to put a park so that it will not inhibit the economic growth of a city, and yet serve the optimum number of people. Other theories will tell you how many floors an office block should have, how large to make the car parks, how many lanes to give the superhighways, and so on. But all these methods, though they are perhaps more precise than an average designer's intuition, still leave the essential structure of the city the same as it was before. If you once agree that houses, streets, parks, and offices, are the proper components of the city (as you have already done, usually, when you even begin to use some systematic method), then there is really very little choice open to you about the city structure. Systematic techniques, just because they need to operate on known units, usually beg the real question of design, and so achieve little more than a second rate designer does. The fundamental change which a structure undergoes at the hands of a great designer, who is able to redistribute its functions altogether, cannot take place if its components stay the same.

II. THE CITY AS AN ADAPTING SYSTEM

Let us now discuss the special nature of the city problem. A city is a live structure, not a dead one. That is, it is a loose assemblage or aggregate of components, which is all the time being added to, and changed.

The form of a city cannot bear the same relation to its needs, as a designed object does. Since the life of the city is always much greater than the life-span of any one pattern of needs, the needs of the city change constantly and unpredictably throughout its lifetime. It is entirely inadequate to treat the city as a building, and to design it by meeting any single pattern of needs, as was done in the case of Brazilia or Chandighar. Even the principle of the master plan, as it is usually practised, which takes into account projected needs, is only a little better, and contains the same fundamental mistake. The span of possible projections into the future is also limited—say it is thirty years.

Even a master plan which looks as far forward as thirty years from now, is still essentially static in its conception; it is still based on the fixed list of needs which are felt now and expected during the next thirty-year interval; whether the programme of needs to be met covers a few years more or less, cannot alter the fact that it invites a design conceived only to meet those fixed needs. If we are honest we know that we cannot see into the future properly; we know that in the future, this city which we are designing now, will generate needs and stresses unimaginable in the year of its design, not calculable by projections into the future; with changes in technology and living habits happening faster all the time, we must devote our attention to the development of what we might call a self-organizing city structure which, apart from meeting present needs, is by nature able to adapt easily to any changes in the pattern of needs whatever, foreseen or unforeseen.

I repeat what I said at the beginning. The city is a live assembly or aggregate of components. The problem of city design is not to design the city as a whole, but really to establish a kit of components out of which such a growing, ever-changing aggregate can be built up. These components will be determined by two properties which the aggregate system must have if it is to maintain its functional efficiency while expanding and changing to meet new needs and circumstances. The first property concerns the addition of new components to the system. The second concerns the modification and replacement of components already in the system.

I will deal first with the addition of new components. It is very certain that we cannot develop all the components of the city simultaneously. We do not have the money, nor the power, nor would it be desirable to cause such an upheaval in the city's life, nor does this correspond to the realities of a city's growth. The city develops gradually. To safeguard its development (as against design), we must define addable 'units' which are sufficiently self-contained, to be used as units of development and aggregation.

We may assure ourselves of the need for this, by looking at some examples from common experience. You may be able to put an artifical heart in a human body. But it would be almost impossible to replace three-quarters of the heart by an artificial three-quarter heart, and leave the other quarter of the natural heart functioning properly together with it. If you enlarge a golf course, you can add an integral number of holes; but you can hardly add a hole and a half. If you prune a tree, you make sure that you cut off limbs and branches at right angles to their length; you know that if you remove half a branch, split lengthwise, you have not left a properly functioning unit. If a foundry and a machine-shop are so well tied together that the machine shop can exactly cope with the castings which the foundry makes, then it is useless to add lathes to the machine shop, without also enlarging the foundry so as to increase its output. Although a lathe looks like a proper 'unit' of development, it is not a proper functioning unit of the 'machine-shop–foundry' ensemble.

This leads to the first axiom: *We cannot add unregulated quantities of elements to a developing structure, but only certain well-integrated units which bear a proper relation to the presently functioning whole. And we cannot change or replace arbitrarily chosen pieces of a functioning whole, but again, only units which are sufficiently well-integrated to function as units or components of the whole.*

It is easy to see that the components defined by work, dwelling, recreation, transportation, are not properly functioning units in this sense. When 50 million families have television in their homes, recreation and dwelling can hardly be treated as separable components. Again, the growing popularity of industrial ring roads like those round Boston or London, makes it doubtful whether work and transportation can be developed as separate components.

The second kind of development which shapes the city, is the modification of the existing fabric as the system encounters new internal needs, and tries to adapt them. It may be easiest to focus on this problem, by seeing what happens when it goes wrong.

Suppose a new kind of centrally distributed piped heat for dwellings becomes commercially feasible. With the city organized as it is today, it would be impossible to install this new piped heat in existing neighbourhoods, because of all the roads and gardens which would have to be dug up. In other words, the installation of piped heat calls for modification of so many of the existing components (dwellings, gardens, streets), that it simply cannot take place.

Take another example. Suppose a new kind of passenger vehicle is invented. It could be very hard for the existing city to adapt to it, because its garaging would affect the dwellings, its circulation would affect the streets, and its storage away from home would affect the recreation and work components. To provide for the new kind of vehicle, so many changes would have to be made, in so many parts of the city, that the city would come to a standstill while these changes were effected.

The same thing will happen when the working week is shortened, and puts more spare time on people's hands. It will have repercussions throughout the city: recreation facilities, homes, roads, will all be affected; again with the result that the modifications will not be made, because they would be too complicated and too widespread to carry out.

In all these cases, instead of the city adapting to the changing way of life, it is the people who bear the brunt of the adaptation by having to carry out new activities in obsolete surroundings. The city itself is unable to adapt to new circumstances as fast as they occur, because each one demands changes in nine-tenths of the city; such extensive changes are impossible, and therefore do not get done.

This failure of adaptation on the part of the city is not caused by the faulty design of the components. You cannot improve it by building better roads or better houses or better parks. The real trouble lies with the root choice of the components; the functions they represent, though perhaps independent to some extent, are not independent enough. What we require, ideally, are components which are so independent, functionally, that every new need and new situation which occurs, only demands change or modification in one of the existing components, instead of all of them. For the sake of example, let us go back to the piped heat. Suppose it were generally recognized, as it should be, that the distribution of telephone, water, mail, and other things from central sources to individual houses, constitutes a bundle of functions, strongly interdependent, and independent of other functions, so that some kind of huge ducting component was a normal part of the city and took care of all these things simultaneously. When the possibility of piped heat came up, it would then be necessary to modify only this one component. All the necessary changes would concern the duct, and nothing else; and as a result the change could be effected; and the adaption to the new situation could actually take place.

The general statement of this principle, which will allow the city to adapt rapidly to future changes, is my second axiom. *If a changing system in contact with a changing environment is to maintain its adaptation to that environment, it must have the property that every one of its subsystems with an independent function is also given so much physical independence as an isolable component, that the inertia of those components which for the time being require no modification, does not make it impossible to modify those other components which do need to be changed.*

To achieve the two properties required by adaptation, this one which I have just stated, and the other stated earlier, the components of the city must themselves have two properties. To satisfy the first axiom, the components must be functionally compact—that is, each must operate as a unit. And to satisfy the second axiom, the components must be highly independent of one another, functionally.

III. THE METHOD

I shall now describe a method of determining components to meet these two conditions. It rests on the assumption that each component of a physical structure represents what we might call a 'coming together' of a number of functional requirements.

A street is the coming together of the need for circulation space, the need for access to houses, the need for light and air between buildings, the need for somewhere to bury services, the need to lead off excess water during rainstorms. All these requirements, because they have similar physical implications, together define the linear component of the city which we call a street. A house is the coming together of the need for somewhere to sleep, the need for a place to store and prepare the food, the need for a place to belong to, the need for a place to raise children, the need for protection from wind and rain. All these requirements come together to form the component of the city we call a house.

A less homely way of putting this is to say that each component of the physical city comes into being to deal with some specific subset or subsystem of requirements in its environment. If we want the components to have the kind of independence and unity described above, the way to ensure this is to put them in 1–1 correspondence with the most independent subsystems of their environment. In other words, establish the truly independent subsystems of requirements in the environment, and then match each one of these subsystems with a physical component of the physical system you are designing. I do this as follows.

Establish, first of all, the requirements which have any bearing on the physical shape of the village. The list which follows includes requirements of every conceivable kind: (1) all those which are explicitly felt by villagers themselves as needs, (2) all those which are called for by national and regional economy and social purpose, and (3) all those already satisfied implicitly in the present village (which are required, though not felt as needs by anybody). Each requirement must be clearly enough defined for it to be decidable in principle in an actual village, whether the requirement is satisfied or not. Beyond that the requirements need have nothing in common. In particular, it is not necessary for each requirement to have a quantifiable performance standard associated with it. In other words, all the variety and vagueness of requirements which we encounter in real world problems can be included.

[In the original there follows a list of 141 requirements.]

Secondly, in order to examine the system properties of the set of requirements, we must decide, for each pair of requirements, whether they are dependent or not. Again, the interactions I accept are not limited to those which can be expressed in the form of equations or other kinds of mathematical functions. Two requirements are dependent if whatever you do about meeting one makes it either harder or easier to meet the other, and if it is in the *nature* of the two requirements that they should be so connected, and not accidental.

Here is an example. 94 is the need for provision for animal traffic. This conflicts with 7, the need for cattle to be treated as sacred, because the sacredness of cattle allows the cattle great freedom, and hence more room for circulation, which makes 94 harder to meet adequately. On the other hand, 94 connects, positively, with 13, the need for family solidarity, because this latter requirement tends to group the houses of family members in compounds, and so reduces the number of access points required by cattle, making 94 easier to meet.

[In the original there follows a complete list of interactions.]

If we think of the requirements as points, and of the dependences between requirements as links, then the set of requirements and the set of links together define a linear graph (or topological 1-complex). This serves as a complete structural description of the functional environment which contains the village and calls it into being.

The beauty of this description is that we can now give it a mathematical interpretation, compatible with the real-world facts, though nonetheless artificial, which suggests criteria for decomposing the system of requirements into subsystems, and these themselves into further subsystems, in such a way that each subsystem contains a set of requirements very densely connected internally, yet as far as possible independent of the requirements in other subsystems.

To do this, we think of each requirement as a binary variable, capable of being in two states (satisfied and unsatisfied). The links between the requirements are interpreted as probabilistic tendencies for the linked variables, to take equal or opposite values. With such an interpretation, where the village's environment appears as a system of interdependent binary variables, the task of finding the environment's subsystems becomes the task of decomposing the set of variables into subsets of variables in such a way that some function expressing the total dependence between the sets is minimized.

To make this clear, I first give the simplest possible way of doing it. If we divide the set of linked points into two sets, some of the links will probably be severed. Obviously if such a partition severs a great many links, then the variables in one set are very much intertwined with those in the other, and the partition is not a good one. On the other hand, if the partition severs fewer links, the two sets are less dependent. If we treat the number of links severed as the criterion function, and minimize this function, we shall have two sets of variables which we might reasonably call independent subsystems.

As it happens, this particular function is over-simple and cannot be justified theoretically. I shall now describe two functions which can be derived from reasonable theoretical premises.

The first function is derived from the problem of establishing components as well-integrated units. It is a measure of the amount of information transmitted by one set of variables to the other:

$$\frac{(\ell - \ell_a - \ell_b)m(m-1)/2. - \ell.a.b}{\sqrt{\{a.b.(m(m-1)/2 - a.b)\}}} *$$

If we partition the variables in such a way as to minimize this function, we get subsystems which are informationally as independent as possible. The derivation and exact purpose of this function are given in my thesis. Minimization according to this function has been programmed for the IBM 7090. It is this function which gave the decomposition of the village problem that follows.

The second function is derived from the problem of having new needs affect no more than one component at a time. Suppose that in the future some new need arises, not at present represented in the set of variables. If the present city is to adapt to this new need successfully, we should hope that only one of the existing city's components need be modified in response to the new need. In other words, we should hope that the existing subsystems are such that this new requirement be linked entirely to those requirements in some one subsystem, and not at all linked to any of the requirements in other subsystems.

Assume that any new requirement is linked to a random selection of the existing requirements, subject to the following condition: A link between two existing requirements makes it slightly more likely that a new requirement will be linked to both of them or neither, and slightly less likely that it will be linked to just one of them. We can then express the total probability of a new requirement being linked to just one subsystem, not to both, for any division of the existing requirements into two subsystems. This probability is given by:

$$\frac{2^b\left(\ell_a - \dfrac{a(a-1)}{m(m-1)}.\ell\right) + 2^a\left(\ell_b - \dfrac{b(b-1)}{m(m-1)}.\ell\right)}{\sqrt{\left\{2^{2b}\cdot\dfrac{a(a-1)}{2}\left[\dfrac{m(m-1)}{2} - \dfrac{a(a-1)}{2}\right] + 2^{2a}\dfrac{b(b-1)}{2}\left[\dfrac{m(m-1)}{2} - \dfrac{b(b-1)}{2}\right] - 2^{a+b}\dfrac{a(a-1)}{2}\cdot\dfrac{b(b-1)}{2}\right\}}}$$

*The parameters used in the functions are to be interpreted as follows:
m the total number of variables
a the number of variables in one subsystem
b the number of variables in the other subsystem
ℓ the total number of links
ℓ_a the number of links entirely within the first subsystem
ℓ_b the number of links entirely within the other subsystem

We partition the variables in such a way as to maximize this probability. I am now in the course of programming this maximization for the IBM 7090.

IV. EXAMPLE

Analysis of the graph defined by the 141 village needs and the links between them, shows that these needs fall into four major subsystems which I have called A, B, C, D; and that these systems themselves break into twelve minor subsystems, A1, A2, A3, B1, B2, B3, B4, C1, C2, D1, D2, D3. Each of these minor subsystems contains about a dozen needs.

A1 contains requirements 7, 53, 57, 59, 60, 72, 125, 126, 128.
A2 contains requirements 31, 34, 36, 52, 54, 80, 94, 106, 136.
A3 contains requirements 37, 38, 50, 55, 77, 91, 103.
B1 contains requirements 39, 40, 41, 44, 51, 118, 127, 131, 138.
B2 contains requirements 30, 35, 46, 47, 61, 97, 98.
B3 contains requirements 18, 19, 22, 28, 33, 42, 43, 49, 69, 74, 107, 110.
B4 contains requirements 32, 45, 48, 70, 71, 73, 75, 104, 105, 108, 109.
C1 contains requirements 8, 10, 11, 14, 15, 58, 63, 64, 65, 66, 93, 95, 96, 99, 100, 112, 121, 130, 132, 133, 134, 139, 141.
C2 contains requirements 5, 6, 20, 21, 24, 84, 89, 102, 111, 115, 116, 117, 120, 129, 135, 137, 140.
D1 contains requirements 26, 29, 56, 67, 76, 85, 87, 90, 92, 122, 123, 124.
D2 contains requirements 1, 9, 12, 13, 25, 27, 62, 68, 81, 86, 113, 114.
D3 contains requirements 2, 3, 4, 16, 17, 23, 78, 79, 82, 83, 88, 101, 119.

We may picture this system of subsystems as a tree (Figure 1).

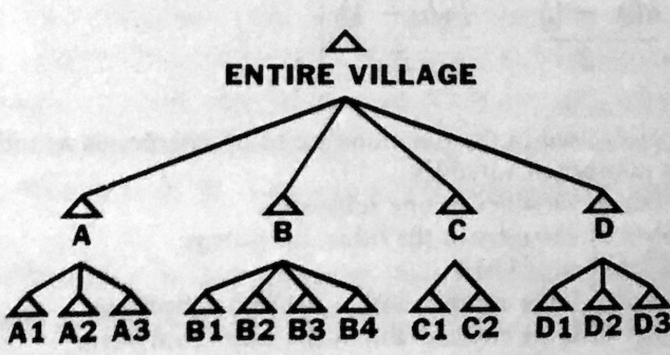

Figure 1

I repeat what I have said before. If we regard this system of needs as the environment, and we regard the village as a physical system of components constantly striving for adaptation to its environment, then we want to put the hierarchy of the village's components, in 1–1 correspondence with the hierarchy of subsystems in the environment. It is under these circumstances that expansion and modification of the village are likely to be most successful. To create this 1–1 correspondence, I have tried to establish, for each of the twelve subsystems of needs, a physical component which meets first the needs in that subsystem, and no other needs. These components are shown in diagrammatic form in the following pages. I have also tried, in the four major diagrams labelled A, B, C, D (Figures 2–5), to show how the minor components might fit together to make the major components, and then in the composite diagram (Figure 6) how A, B, C, D themselves might fit together to make an entire village.

I first give a summary of the components, and the way they fit together, so that the more detailed account of each component and the functions which belong to it may be better understood.

The four main components are roughly these: A deals with cattle, bullock carts, and fuel; B deals with agricultural production, irrigation, and distribution; C deals with the communal life of the village, both social and industrial; D deals with the private life of the villagers, their shelter, and small-scale activities. Of the four, B is the largest, being of the order of a mile across, while A, C, D are all more compact, and fit together in an area of the order of 200 yd across.

The basic organization of B (Figure 2) is given by the component B4, a water collector unit, consisting of a high bund, built in the highest corner of the village, at right angles to the slope of the terrain; within the curve of this bund, water gullies run together in a tank. This tank serves the rest of the village land, which lies lower, by means of sluices in the bund; the component B4 is intimately connected with B3, the distribution system for the fields. The principal element of this component is a road elevated from floods, which naturally takes its place along the top of the bund defined by B4. At intervals along this road, distribution centres are placed providing storage for fertilizer, implements, and seeds; in view of the connection with B4, each one of these centres may be associated with a sluice, and with a well dug below the bund, so that it may also serve as a distribution centre for irrigation water. Each distribution centre serves one unit of type B2; this is a unit of cooperative farming broken into contoured terraces by anti-erosion bunds and minor irrigation channels running along these bunds. B1 is a demonstration farm surrounding the group of components ACD, just at those points of access which the farmers pass daily on their way to B2 and B3.

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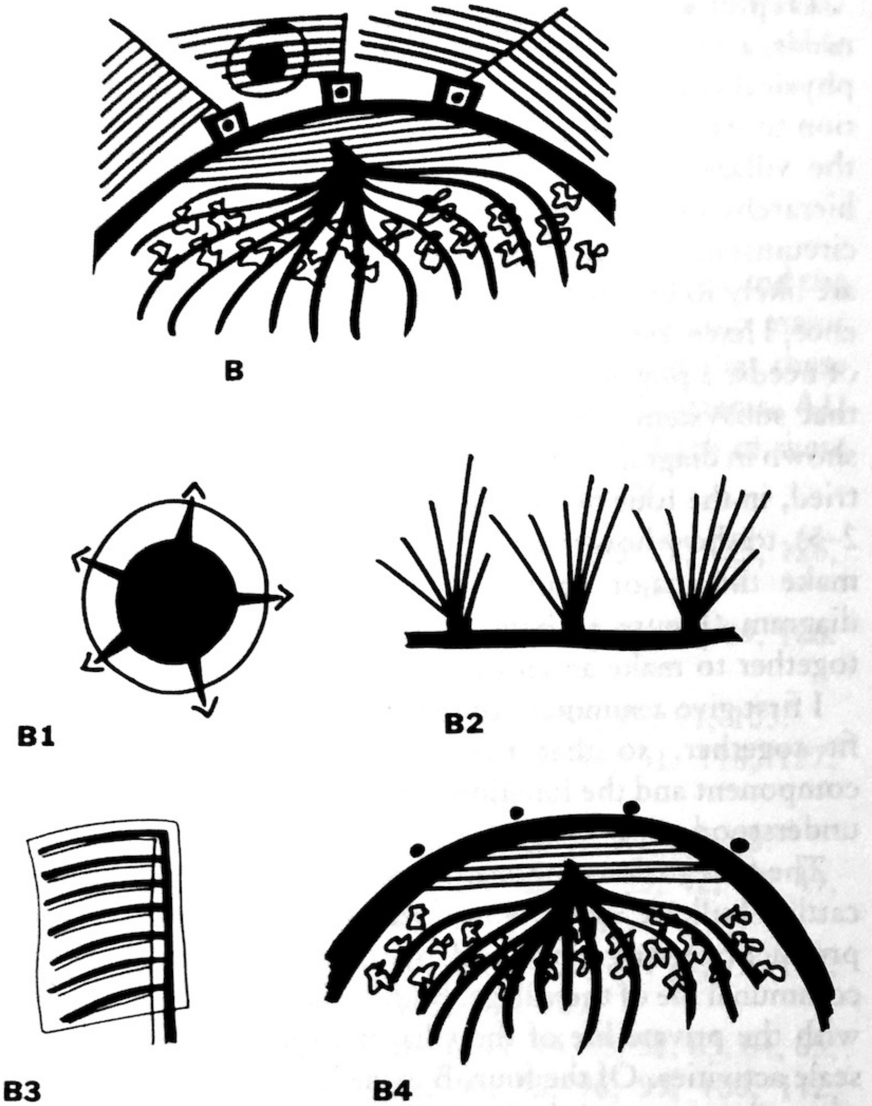


Figure 2

The smaller group of components ACD is given its primary organization by the fact that several units of type D must function together (Figure 3). Each D copes with the small-scale activities of about 50 people. It is defined by D2, a compound wall carrying drinking water and gas along its top. At the entrance to the compound, where the walls come together, is a roofed area under which cottage industries take place. The compound contains the component D1, an assembly of storage huts, connected by roofed verandahs which provide living space. Every third or fourth hut has a water tank on top, fed by the compound wall, and itself feeding simple bathing and washing-up spaces behind walls. D3 is a component attached to the entrance of the compound; it provides a line of open water at which women may wash clothes, trees with a sitting platform at their base for evening gossip, in such a way that the water and trees together form a climatic unit influencing the microclimate of the compound, and also, because of the water and trees, offering a suitable location for the household shrine.

C (Figure 4) is made of two components; C2 is a series of communal buildings (school, temple, panchayat office, village

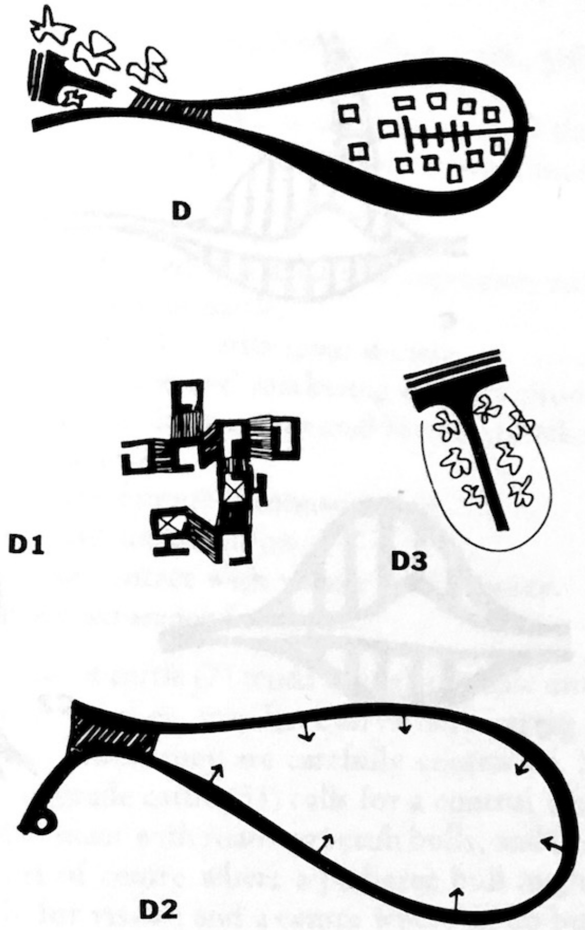
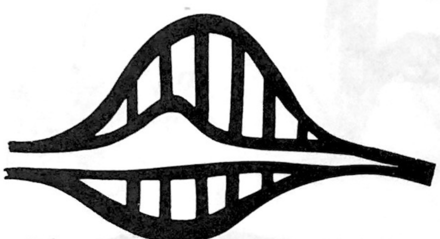


Figure 3

meeting place, etc.) each with a court, the courts opening in alternatingly opposite directions. The cross walls are all pierced by gates, in such a way that there is a continuous path down the middle of the component. This path serves as a connecting link between different centres, a processional route, and pedestrian access to the compounds D which may therefore be hung from C2 like a cluster of grapes. One end of this component C2 runs into C1; C1 is a widening of the road on the bund; on this widening out, a number of parallel walls are built to mark out narrow, urban-like plots. There is in the centre of these plots a bus stop, opening out of the road itself. The whole unit houses whatever industry, power sources, and other aspects of the village's future combine base, develop.

The structure of A (Figure 5) starts with A2, a group of cattle stalls, each stall opening towards the outside only, its floor falling towards the centre, with a drain in the centre leading all manure to a pit where the slurry for the gober gas plant can be prepared. Each compound has such a component A2 in its centre, between the pieces of D1; exit from the compound, for cattle and carts, is by way of component A3, a gate in the compound wall, marked by the cattle trough and the gober gas plant itself. A group of several components A2 and A3 are tied together by the single A1. A1 consists of a central control point through which all cattle leaving any compound, have to pass.

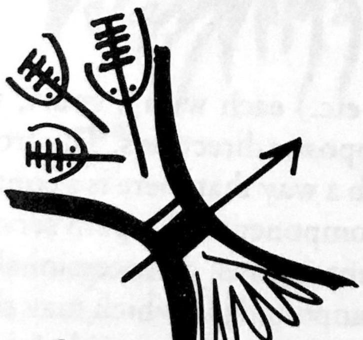
C



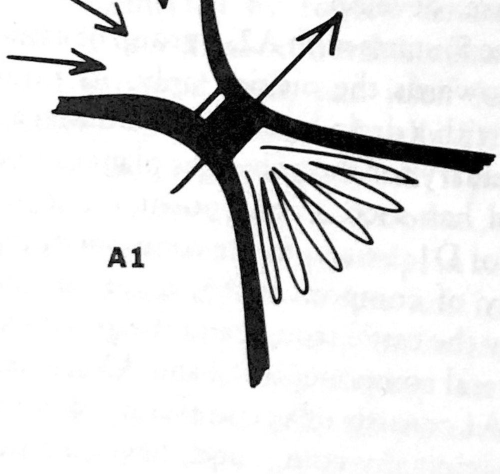
C1

C2

Figure 4

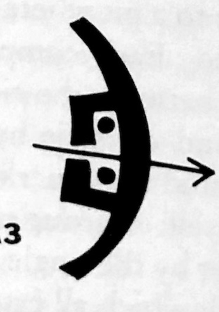


A



A1

A2



A3

Figure 5

This control point provides a hoof bath, a dairy, and a link to the main road via C1.

There now follows a more detailed account of the reasons behind the organization of each of the twelve minor components.

A1: 7. Cattle treated as sacred and vegetarian attitude.
53. Upgrading of cattle.
57. Protection of cattle from disease.
59. Efficient use and marketing of dairy products.
60. Minimize the use of animal traction to take pressure off shortage.
72. Prevent famine if monsoon fails.
125. Prevent malnutrition.
126. Close contact with village level worker.
128. Price assurance for crops.

The sacredness of cattle (7) tends to make people unwilling to control them, so they wander everywhere eating and destroying crops, unless they are carefully controlled. Similarly, the need to upgrade cattle (53) calls for a control which keeps cows out of contact with roaming scrub bulls; and further calls for some sort of centre where a pedigree bull might be kept (even if only for visits); and a centre where scrub bulls can be castrated. Cattle diseases (57) are mainly transferred from foot to foot, through the dirt—this can be prevented if the cattle regularly pass through a hoof bath of disinfecting permanganate. If milk (59) is to be sold cooperatively, provision must be made for central milking (besides processing); if cows are milked at home, and the milk then pooled, individual farmers will adulterate the milk. Famine prevention (72), the prevention of malnutrition (125), and price assurance for crops (128) all suggest some kind of centre offering both storage, and production of nourishing foods (milk, eggs, groundnuts). If

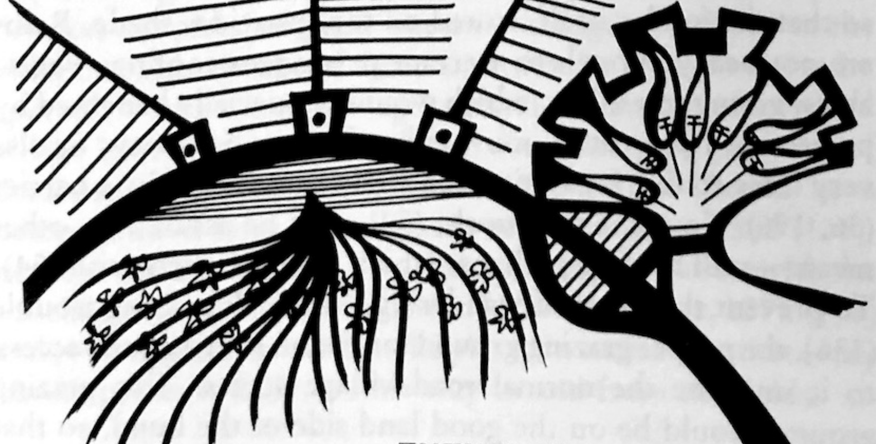


Figure 6

the village level worker (126) is to come often to the village and help, quarters must be provided for him here. Animal traction (60) calls for access to and from the cattle stalls (A2) on the one hand, and the road on the other.

A2: 31. Efficient distribution of fertilizer, manure, seed from village storage to fields.
34. Full collection of natural manure (animal and human).
36. Protection of crops from thieves, cattle, goats, monkeys, etc.
52. Improve quantity of fodder available.
54. Provision for feeding cattle.
80. Security for cattle.
94. Provision for animal traffic.
106. Young trees need protection from goats, etc.
136. Accommodation of wandering caste groups, incoming labour, etc.

Here (31, 34, 54, 80, 94) form a subset connected with cattle movement and manure, while (36, 52, 106, 136) form a subset mainly concerned with the protection of crops and trees from wandering cattle. (31) and (34) call for the collection of urine and dung, which suggests cattle should be in one place as much of the time as possible, where there is a pucca floor draining towards a central manure collector. This is of course closely connected with feeding stalls, the most permanent standing place for cattle. (80) calls for psychological security—cattle owners want their cattle as near to them as possible, if not actually in the house, and therefore absolutely opposed to the idea of a central communal cattle shed. In view of disease and germ breeding difficulties the closest arrangement possible seems to be one where individual stalls are immediately opposite owners' verandahs with nothing but a path between; this path serves to accommodate cattle traffic (94). Each stall is marked by its walls, roofed only by wood purlins at 2 ft centres, so that the fodder itself, stored on top, provides shade. Rains are not heavy enough to warrant permanent roofing. Vegetables, young trees, etc., which would be specially benefited by protection from cattle, must either be very far away, or else very close so that separation can really be achieved by a barrier (36, 196). To make this work, (52) must be assured by other means—stall feeding perhaps, which then connects with (54). To prevent the cattle of wandering shepherds causing trouble (136), the proper grazing ground must abut the road, the access to it must be the normal road–village access. This grazing ground should be on the good land side of the bund, so that when green silage is introduced, land can be irrigated and cultivated.

A3: 37. Provision of storage for distribution and marketing crops.
38. Provision of threshing floor and its protection from marauders.
50. Protected storage of fodder.
55. Cattle access to water.
77. Village and individual houses must be protected from fire.
91. Provision and storage of fuel.
103. Bullock cart access to house for bulk of grain, fodder.

Access for cattle to water (55) should be to good water, hence to drinking water distribution system, feeding off compound wall D2. (77) and (91) are best achieved by a controlled fuel supply, like gas, supplied by a gober gas plant using manure from A2, the gas distributed to individual kitchens by the same artery that distributes water, i.e. the compound wall.

At the point on the compound wall indicated by these previous items, there must be an opening to allow passage of bullock carts (103), and at this point there should also be a store for supplies and fodder—or at least an easy unloading and access point to the roofs of the cattle bays (37, 38, 50).

B1: 39. Best cotton and cash crop.
40. Best food grain crop.
41. Good vegetable crop.
44. Crops must be brought home from fields.
51. Improve quality of fodder available.
118. Demonstration projects which spread by example.
127. Contact with block development officer.
131. Panchayat must have more power and respect.
138. Achieve economic independence so as not to strain national transportation and resources.

(39, 40, 41, 51) and economic independence (138) are all items which can only be improved by the widespread use of improved agricultural methods; these are not directly dependent on the physical plan, but on a change of attitude in the villagers. This change of attitude cannot be brought about by sporadic visits from the agricultural extension officer and village level worker, but only by the continuing presence of demonstration methods, on site, (118); there should be a demonstration farm, government or panchayat owned (131), perhaps run by the village level worker in association with the panchayat (hence accommodation for such officers, 127). (118) and (44) suggest that the farm be placed in such a way that every farmer passes it daily, on his way to and from the fields.

B2: 30. Efficient and rapid distribution of seeds, fertilizer, etc., from block HQ.

35. Protection of crops and insects, weeds, disease.
46. Respect for traditional agricultural practices.
47. Need for new implements when old ones are damaged, etc.
61. Sufficient fluid employment for labourers temporarily (seasonally) out of work.
97. Minimize transportation costs for bulk produce (grain, potatoes, etc.).
98. Daily produce requires cheap and constant (monsoon) access to market.

(97) and (98) are critical, and call for access to and from the fields on a road which is not closed in the monsoon; i.e. on an embankment. (30) and (35) call for efficient distribution within the plots, of seeds, fertilizers, insecticides, etc., which must themselves be stored at some point where delivery is easy—i.e. on the road. Hence the idea of distribution centres located at intervals along the main road, serving wedge-shaped or quasi-circular units of agricultural land. (46, 47, 61) have little discernible physical implication.

B3: 18. Need to divide land among sons of successive generations.
19. People want to own land personally.
22. Abolition of Zamindari and uneven land distribution.
28. Proper boundaries of ownership and maintenance responsibility.
33. Fertile land to be used to best advantage.
42. Efficient ploughing, weeding, harvesting, levelling.
43. Consolidation of land.
49. Cooperative farming.
69. Fullest possible irrigation benefit derived from available water.
74. Maintenance of irrigation facilities.
107. Soil conservation.
110. Prevent land erosion.

(18–49) all point to the development of cooperative farms of some sort, from the point of view of increasing efficiency of resources, manpower, machines, better crops, rotation of crops, etc. (69) cannot be implemented unless water is distributed from the HQ of such cooperatives because otherwise faction and personal rivalries, etc., prevent full use of wells—i.e. warring neighbours adjacent to the source of water (well) will not agree to cooperate about sharing its use. (74) irrigation requires consolidated ownership of channels, otherwise neglect at one place holds up the efficient use somewhere else. (107) soil conservation depends on rotation of crops, which is only feasible if large plots are under single ownership control, so that they can carry the full pattern of rotation. (110) erosion is prevented by long continuous contour bunds, which can only be put across land of integrated ownership. Bund and irrigation divisions on contours suggest terraced strips of land as units of cooperative farm, fed from single uphill source.

B4:
32. Reclamation and use of uncultivated land.
45. Development of horticulture.
48. Scarcity of land.
70. Full collection of underground water for irrigation.
71. Full collection of monsoon water for use.
73. Conservation of water resources for future.
75. Drainage of land to prevent waterlogging, etc.
104. Plant ecology to be kept healthy.
105. Insufficient forest land.
108. Road and dwelling erosion.
109. Reclamation of eroded land, gullies, etc.

(32) and (48) call for use of wasteland, which often contains river bed area. (48) calls for irrigation of this area. (71, 73, 75) suggest the use of monsoon water instead of and as well as well water for irrigation, since well irrigation is temporary in the long run, because it causes a drop in the water table. Apart from actually using monsoon water for irrigation, the water table in the wells can be preserved if the wells are backed up by a tank. Hence a curved bund, collecting water above wells placed under the bund (70). Rainfall in the catchment area (again a water resource issue (73)) will be improved by tree planting (104, 105) which suggests putting fruit trees (45) inside the curve of the bund. (Incidentally, placing the trees within the bund offers us a way of protecting young trees from cattle, by keeping the cattle on the other side of the bund, which then forms a natural barrier.) Further, if water is to flow toward tank, horizontal contour bunds cannot be used to check erosion as they are in B3, so erosion of gullies, streams, etc., can only be controlled by tree planting (109). Road erosion is controlled if the road is on top of the bund itself (108).

C1:
8. Members of castes maintain their caste profession as far as possible.
10. Need for elaborate weddings.
11. Marriage is to person from another village.
14. Economic integration of village on payment in kind basis.
15. Modern move towards payment in cash.
58. Development of other animal industry.
63. Development of village industry.
64. Simplify the mobility of labour, to and from villages, and to and from fields and industries and houses.
65. Diversification of village's economic base—not all occupations agricultural.

66. Efficient provision and use of power.
93. Lighting.
95. Access to bus as near as possible.
96. Access to railway station.
99. Industry requires strong transportation support.
100. Bicycle age in every village by 1965.
112. Access to a secondary school.
121. Facilities for birth, pre- and post-natal care (birth control).
130. Need for increased incentives and aspirations.
132. Need to develop projects which benefit from government subsidies.
133. Social integration with neighbouring villages.
134. Wish to keep up with achievements of neighbouring villages.
139. Proper connection with bridges, roads, hospitals, schools proposed at the district level.
141. Prevent migration of young people and harijans to cities.

This is composed of two major functional sets: (11, 64, 95, 100, 112, 121, 133, 134, 139) which concerns the integration of the village with neighbouring villages and with the region, and (8, 10, 14, 15, 58, 63, 65, 66, 93, 96, 99, 130, 132, 141) which concerns the future economic base of the village, and all the aspects of 'modern' life and society.

These two are almost inseparable. They call for a centre, away from the heart of the village, on the road, able because of being on the road, to sustain connections between the village and other villages (11) and capable of acting as a meeting place for villagers of different villages (112, 121). This function is promoted by the need to provide a bus stop (95), village industries with optimum access to the road (63–66, 99), the social gathering place connected with the bus and with jobs made available by the industries (133, 134, 61); the development of a modern and almost urban atmosphere to combat migration of the best people to cities (141), and to develop incentives (14, 15, 130, 132). A centre of industry to promote (8, 63, 64). The road satisfies (64, 95, 96, 99, 100, 139). The centre will be the natural physical location for sources of power and electricity transformer (66, 93); also the most efficient place for the poultry and dairy farming which require road access (58); the bus stop is the natural arrival place for incoming wedding processions (10).

C2: 5. Provision for festivals and religious meetings.
6. Wish for temples.
20. People of different factions prefer to have no contact.
21. Eradication of untouchability.

24. Place for village events—dancing, plays, singing, etc., wrestling.
84. Accommodation for panchayat records, meetings, etc.
89. Provision of goods, for sale.
102. Accommodation for processions.
111. Provision for primary education.
115. Opportunity for youth activities.
116. Improvement of adult literacy.
117. Spread of information about birth control, disease, etc.
120. Curative measures for disease available to villagers.
129. Factions refuse to cooperate or agree.
135. Spread of official information about taxes, elections, etc.
137. Radio communication.
140. Develop rural community spirit: destroy selfishness, isolationism.

The major fact about the communal social life of the village is presence of factions, political parties, etc.; these can be a great hindrance to development (20, 129). If the various communal facilities of the village (5, 6, 24, 84, 89, 111, 115, 120, 137) are provided in a central place, this place will very likely get associated with one party, or certain families, and may actually not contribute to social life at all. On the other hand, it is important from the point of view of social integration (21, 140) to provide a single structure rather than isolated buildings. What is more, isolated buildings also have possible connection with the single family nearest them, which can again discourage other families from going there. What is required is a community centre which somehow manages to pull all the communal functions together, so that none is left isolated, but at the same time does not have a location more in favour of some families than others. To achieve this, a linear centre, containing some buildings facing in, some out, zigzagging between the different compounds is necessary. This also meets (102) the need for processions with important stopping places; and adult literacy calls for a series of walls along the major pedestrian paths, with the alphabet and messages written in such a way that their continuing presence forces people to absorb it (116, 117, 135).

D1: 26. Sentimental system: wish not to destroy old way of life. Love of present habits governing bathing, food, etc.
29. Provision for daily bath, segregated by sex, caste, and age.
56. Sheltered accommodation for cattle (sleeping, milking, feeding).
67. Drinking water to be good, sweet.

76. Flood control to protect houses, roads, etc.
85. Everyone's accommodation for sitting and sleeping should be protected from rain.
87. Safe storage of goods.
90. Better provision for preparing meals.
92. House has to be cleaned, washed, drained.
122. Disposal of human excreta.
123. Prevent breeding germs and disease starters.
124. Prevent spread of human disease by carriers, infection, contagion.

Houses, as they are used at present, are chiefly store-rooms; people actually live on their verandahs most of the time. The one thing which inner rooms provide, namely privacy and psychological security, appears among the needs to be met by D2, not here. Hence, we solve (87) by providing store-rooms, which in a column like manner support verandah roofs stretching between them (85). (26) is mainly concerned with bathing and food, connected with (67, 29, 90) these suggest a water store on top of occasional store houses, with kitchen and bath wall attached to this store (also 122); probably this water store will be fairly close to the source of water as we shall see when we combine this with D2. (76) the floor of the verandah must be raised to keep it out of flood water—also the compound should drain towards the centre to remove the dangers of (92, 123, 124). (56) calls for a space to house A2.

D2:
1. Harijans regarded as ritually impure, untouchable, etc.
9. Members of one caste, like to be together and separate from others, and will not eat or drink together with them.
12. Extended family is in one house.
13. Family solidarity and neighbourliness even after separation.
25. Assistance for physically handicapped, aged, widows.
27. Family is authoritarian.
62. Provision of cottage industry and artisan workshops and training.
68. Easy access to drinking water.
81. Security for women and children.
86. No overcrowding.
113. Good attendance in school.
114. Development of women's independent activities.

(1, 9, 12, 13) suggest group compounds, as they are found at present, each of about 5 to 10 families, i.e. 25 to 50 persons. To provide security (81), especially for women surround it by a wall, whose top serves as a distribution channel for water (68). The fact that the space within the wall is all protected, allows women more freedom within the compound for women's communal activities (114), gives more freedom to widows (25), and allows cottage industries, which are likely to be run largely by women, to flourish (62). The space for cottage industry (62) should go at the entrance to the compound, where women going to and fro from washing activities pass it constantly; this may to some extent combat the effects of purdah (27); encourges women to come out from their houses (which the rooms of a usual house discourages, because it allows women to shut themselves up in seclusion), and may even help girls' attendance in school by making the women more bold (113). Since containing walls are moved outward, overcrowding is less likely to take place (86)—adjustment and expansion can take place more easily within the compound walls, than within individual house walls.

D3:

2. Proper disposal of dead.
3. Rules about house door not facing south.
4. Certain water and certain trees are thought of as sacred.
16. Women's gossip extensively while bathing, fetching water, on way to field latrines, etc.
17. Village has fixed men's social groups.
23. Men's group chatting, smoking, even late at night.
78. Shade for sitting and walking.
79. Provision of cool breeze.
82. Provision for children to play (under supervision).
83. In summer people sleep in open.
88. Place to wash and dry clothes.
101. Pedestrian traffic within village.
119. Efficient use of school; no distraction of students.

Here there are several overlapping functions. (23, 78, 79, 82, 83) all require the control of climate—in particular getting cool conditions—which can be best achieved by the juxtaposition of water and trees. (16, 17, 23, 88, 101) require a unit for gossip, washing clothes, meeting purposes, at the compound level. (2, 3, 4) demand the construction of a place with certain qualities of sacredness, perhaps quiet, water, neem trees. Pedestrian traffic and quiet are called for again by (101, 119). All these functions call for a unit in which water, trees, washing facilities, pedestrian movement, sitting under the trees are juxtaposed; the unit fits directly onto the compound, just outside the entrance. Washing may be either on ghats, etc., or on steps fed from the water wall unit D2.

In conclusion I should like to emphasize the following points:

1. The diagram I have shown for the entire village is only one way of putting the components together. There are many many ways of doing it. The way they fit together in any

actual case will depend on local peculiarities of site and population.

2. It is not at all necessary that these components be introduced into an existing village structure all at once. In fact, although the components do function well in company with one another, each one of the twelve is capable of being introduced into the fabric of an existing village by itself. It is just this that I mean by calling these components the proper units of development.

REFERENCES

The theory this paper is based on is to be found in Christopher Alexander, "Notes on the synthesis of form", Ph.D. thesis, Harvard University, 1962.

The computer program for decomposing a graph, according to the function described on page 41, is written up in Christopher Alexander and Marvin Manheim, *Hidecs 2; A Computer Program for the hierarchical decomposition of a set with an associated linear graph*, Civil Engineering Systems Laboratory Publication No. 160, MIT June 1962.