CHAPTER SIX

GENERATED STRUCTURE

WITH SPECIAL ATTENTION TO THE DIFFERENCE BETWEEN GENERATED AND FABRICATED STRUCTURE AND THE HUGE ECONOMIC COST TO OUR SOCIETY OF THE FABRICATED STRUCTURES WHICH ARE CREATED BY CONTEMPORARY ARCHITECTURE

1 / COMPLEXITY

In this chapter, I shall begin to express, operationally and concretely, what real complexity is when we encounter it in a part of the built environment that has life.

Ostensibly, we are surrounded by complexity. The modern city is immensely complex. Buildings are complex. Ecosystems, and the biosphere are still more complex. Computers and computer networks, and software, are all enormously complex. It would be natural to expect, therefore, that we must have a theory of complexity, that we have an effective and sensible way of thinking about the best way to *create* complexity. Faced with the need, growing every day, to create successful complex structures all around us, one would expect that we have at least asked ourselves *how*, in general, a complex structure may become well-formed. We should long ago have asked ourselves this most basic question: *Is the way that we view design, planning, and construction — in all the spheres mentioned, ecosystems, buildings, communities, objects, computers and computer software — the right way to produce sufficient complexity, and does what we are doing have a chance of success?*

And the answer is, that there is a fundamental law about the creation of complexity, which is visible and obvious to everyone — yet this law is, to all intents and purposes, ignored in 99% of the daily fabrication processes of society. The law states simply this: ALL *the well-ordered complex systems we know in the world, all those anyway that we view as highly successful, are* GENERATED *structures, not fabricated structures.*

The human brain, that most complex neural network, like other neural networks, is generated, not assembled or fabricated. The forests of the Amazon are generated, not fabricated. The tiger, beautiful creature, is generated, not fabricated. The sunset over the western ocean with its stormy clouds, that too is generated not fabricated. When we make a fire that really burns, we generate its structure, by placing a few logs, strategically, to create currents of air, radiation between glowing embers, so that the structure of the fire then creates itself. When we cook a souffle, we generate the souffle by initiating transformations among eggs, butter, sugar, and so on: we do not try to build it, like an inept bunch of chopped vegetables, that someone likes to call a salad. Music, possibly most among all things, is generated, even when stimulated by a score: and it may be generated by a more elusive combination of chords and rhythms that "get something going." All this, is true of buildings, too, and of our communities.

2 / THE GEOMETRY OF COMPLEXITY

In broad terms, a generated structure is something that has a certain deep complexity and is created in some way that appears to be almost biological, and reaches deeper levels of subtle structure than we commonly associate with "design," or with designed objects. In a generated structure one feels intuitively, above all that the structure is more complex and more subtle than anything that could be designed or fabricated.

To get a detailed grip on the nature of this generated complexity, we need a perspective which focuses, above all, on the *geometry* of what has been generated. Further, it is a particular aspect of the geometry we are concerned with. We may identify a particular visible physical character of the environment — its "generatedness" — as the sign that it has been made by a living process.

Generated structure: Jaisalmir, Rajasthan, India. Here the wishes of the family, their comfort, and the adaptation of use to structure have been simply carried out, without fuss, all quite direct. Contrast this picture with the photograph on page 184.

For all these reasons, I devote this chapter, almost entirely, to the generated structure of *the geometry* which follows from living process.

When a process creates living structure, we at once see the impact of the process in the geometry as that something that seems like "generated structure." We see it in the photograph on this page. And we see it in the plan illustrated below, on page 182. The geometry is always, when living, what we may recognize as "*Generated*." This is the adjective which best captures what we are looking for, and that will become the talisman of our success in trying to implement a living process. Does the process create generated structure, or doesn't it? This is a most useful practical question, in trying to decide whether a particular process is a living one.

The need to make all parts of the environ ment as generated structures, once established, will help guide us to see the various attributes of living process, in detail. Our search for adequate definitions of living process can then be guided and stimulated by this focus on the geometry of the results.

Once we have the geometry of complexity fixed in our minds as a target, we may then understand better the purpose of the chapters which follow, and will understand that each of the features of living process covered in subsequent chapters, is specifically intended to make the generation of living structure — in its real and necessary complexity — achievable, possible, and likely to succeed. Throughout the discussion, I shall use the concept of a generated structure, and use this term in opposition to the concept of a fabricated structure.

3 / ANALYSIS OF A FEW GENERATED STRUCTURES BY MEANS OF EXAMPLES

A

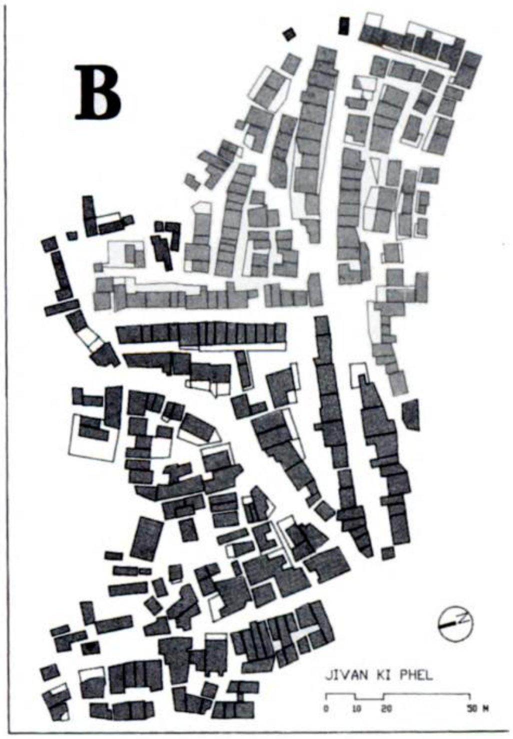
A: A generated structure: Shilnath, Indore, India.

On pages 181–85 there are seven plans of settlements in India. Three of them (A, B, C) are generated structures. Four of them (D, E, F, G) are fabricated structures.[1]

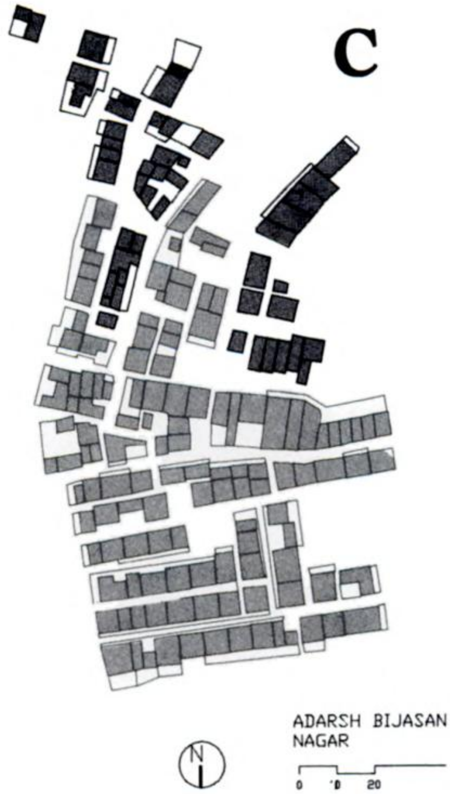
What is it about A, B and C that is different? I should like to suggest, first of all, that most of us share an immediate perception that A–C are more *interesting* than D–G: more complex, more difficult to describe, richer, and somehow more important.

We may feel this in many ways. One person may feel that A–C are more interesting simply as works of art, more interesting to look at, would hold the attention better artistically, if (as plans) they were hung on a wall. D–G are boring, too simple, one stops looking at them after a few moments.

At a slightly more sophisticated level, looking carefully at the plans as plans *of human settlements*, we can see immediately, that A–C are bet-



B: A generated structure: Jivan Ki Phel, Indore, India.



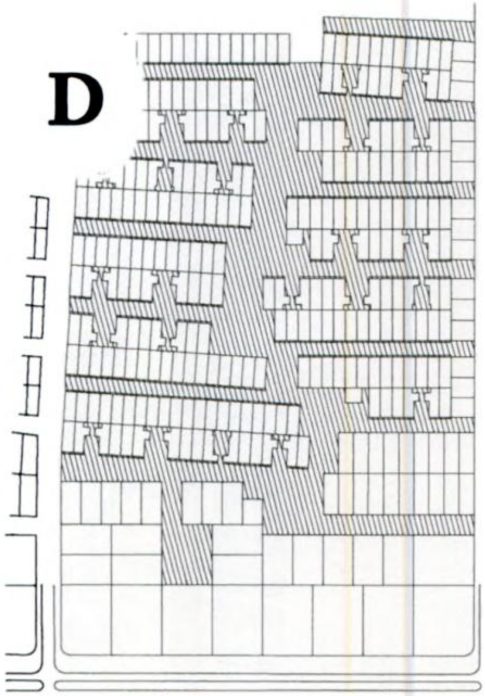
C: A generated structure: Adarsh Bijasan Nagar, Indore, India.

ter places to live than D–G. The houses are more differentiated; spaces are more satisfying; the experience of being there is richer, each house is unique in shape and position; there are more, and denser, patterns of significant relationships between houses and spaces. With D–G the experience of the actual place will be more sterile, it is less rewarding to be there. Altogether as human, social, and emotional environments, they are less satisfying than A–C.

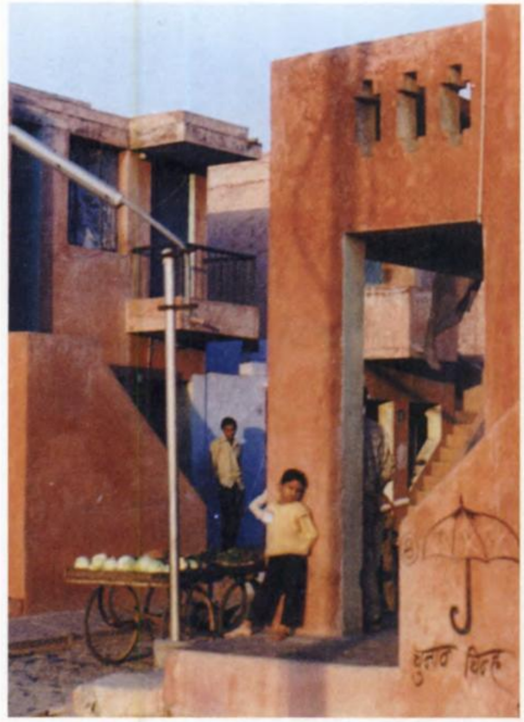
At least intuitively it is clear, then, that there is something more interesting, more important about A–C than about D–G. The difference hints at something interesting. But what does it mean, what is responsible for the difference we see, and what is the meaning of the difference we see? What is it that makes them profound, what distinguishes them?

My purpose in bringing this out is to ask what the difference is between the two *classes* of objects. What is it about the two classes, *precisely*, that makes the generated structures more interesting and more important?

The concept of "generated" is not quite as straightforward as it seems if one merely looks at the geometry of the plan. For example, architects have thought for two or three decades now, that, in various ways they can simulate the beauty and living character of generated structures and achieve results of greater variety and beauty by doing so. The plan F was made by Rajinder Puri, visibly in an attempt to reproduce the variety of space, the variety of house sizes, and the overall more dynamic character of the generated examples. Yet it still lacks the essential quality of generated structures, and must be firmly placed in the fabricated camp. Its arrangement is created by design, and seems better only in appearance. The essence of its fabricated character is untouched.

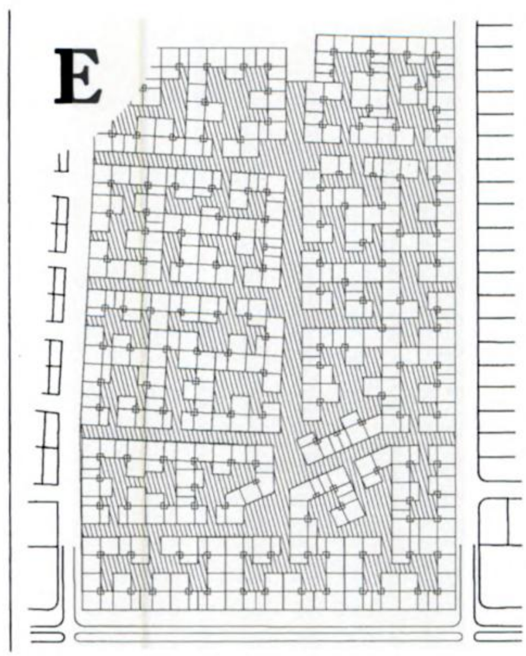


D: A fabricated structure: designed by B. V. Doshi, Vastu Shilpa, and built in Indore around 1989.

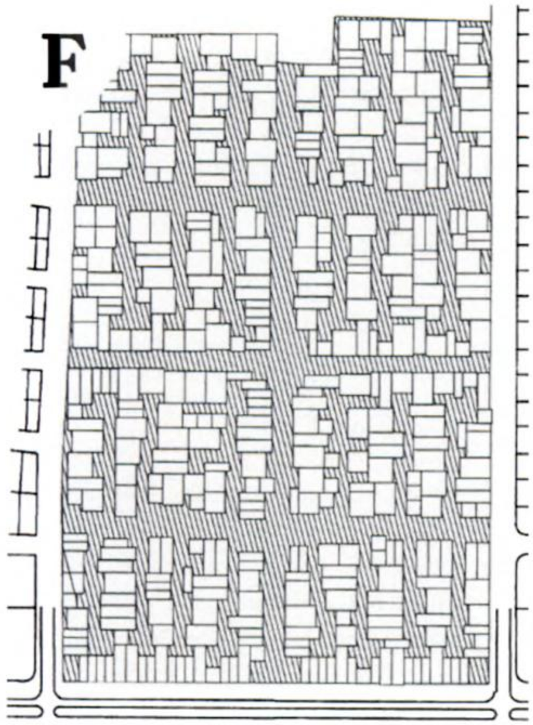


The houses built as part of plan D. Although there was a sincere effort to involve families in decisions, it is plain that this is not a generated structure, and the family input has not deeply led to emergence of living structure. Contrast this with the photograph on page 181.

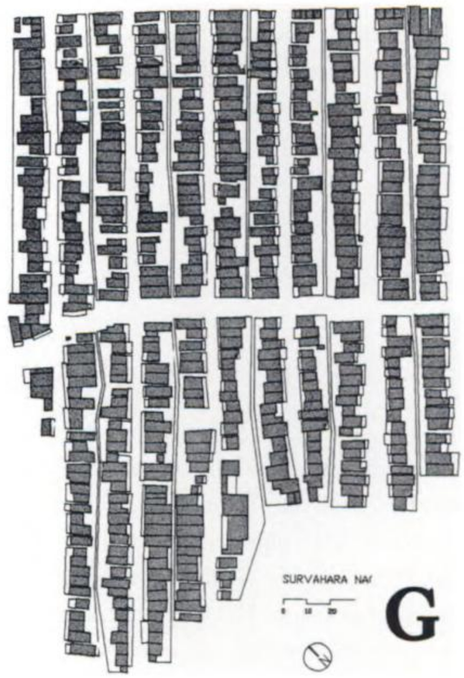
The Plan D was made by my old friend Balkrishna Doshi. In this case the whole idea of the plan is to create a living character by allowing families to make their own house for themselves, plainly a positive ideal, and one which has laid important steps as a precedent. But here, too, the plan itself, its ins and outs, are mechanical — I do not want to say contrived, since they are plainly made with good intent, and with the purpose of making a better living environment. This project was built as drawn, in 1989, and did achieve an important measure of success, as living structure, because of the individually designed house layouts allowed within the rigid structure of the plan. Yet the most important variables which should have been under control of the families, are fixed. The families' contributions are hardly more than minor cosmetic variations within a rigid shell. So this plan, too, lacks the *essence* of living structure, and is not a generated structure. It, too, must be placed in the fabricated camp.



E: A fabricated structure: designed by Carlos Barquin, a theoretical study for Indore, India.



F: Planned settlement by Rajinder Puri, making an effort to create the appearance of a generated structure, but within the framework of a fabricated structure.



G: A fabricated structure: government-designed public housing, Indore, India. The project has had some modest changes over time, which are visible in the in-and-out character of individual dwellings. However, as a whole, the community remains a fabricated structure.

At first sight Plan G looks more generated, and less fabricated than D, or E, or F. And indeed it has more of the character of a generated structure, within the framework of a fabricated one. It is an actual place, made by architects and inspired by a government program of public housing. However, it seems generated only because the houses are all slightly different, house fronts wobble, and the street has minor jigs in it. The variation is a little more real, a little more genuine, than that in plan F, for example. But, although there is an aspect of this plan G that is truly generated, again what is allowed to vary is only a very small proportion of what matters. The core of the plan, most of what one experiences in the actual place, is a lack of living structure at intermediate levels of scale, shows that in its essential quality this plan is still independent of human reality in the houses and in the social groupings: The plan is still a fabricated one.

4 / STRUCTURES THAT HAVE UNFOLDED IN TIME

In the generated structures A–C we have a strong sense that they unfolded over time. We have a feeling, an intuitive certainty that the plans could only have been generated over time. On the other hand, in D–F it is very clear that the design was created at one moment in time as an *arrangement*. Of course, in a certain sense, D, E and F, too, were created in time. Although the time scale may have been shorter, they still happened in time. The design did not appear all at once in one nanosecond. It may even have taken months at the drawing board to create them. Yet in D–F this length of time is not significant. We know that A–C happened in time in some *meaningful* way, and in a way which mattered, and which gave them their deep essential structure. In D–F, the role of time is insignificant, trivial. Time did not affect the structure, or contribute to its design.

We shall, in the next half-dozen pages, try to understand just what exactly this is, this "meaningful" way.

5 / HOW TO COUNT MISTAKES

When we examine an object, we may see that each element in the object (part, line, edge, position, color, size) represents a decision. In very rough terms, we may say that each line represents a different decision. We may also say that each line has created space on either side of it and near it, and therefore typically represents some four or five decisions about space (through size, convexity, adjacency, organization).

In addition, we must be conscious that larger elements, too (streets, house groups, courtyards, party walls, paths, blocks) — not only the smallest elements — must be included among the elements considered, and decisions about size, shape, and position of these larger elements, too, must be counted, since these also may be either flawed (with mistakes) or well-adapted. In the Shilnath plan (A) there are 150 house lots. Each house lot, as shown on this plan, has possibly four or five lines associated with it, making a total of say, 700 elements or decisions at the lowest level of scale. In addition, we may guess that there are potentially half as many again larger-level elements at a wide variety of different scales. Thus there are about 1000 elements in all, in the Shilnath plan.

Each element has the possibility of being wrong. By that I mean that the element as placed, sized, and oriented, may be *well-adapted* to its neighbors, to the space around it, to the conditions which exist, and to the conditions arising from the structure of the surrounding elements — or it may be *badly adapted* to the neighbors, conditions, space, trees, arising from surrounding elements.

We are going to count the number of possible mistakes, and try to estimate how mnay of these mistakes have been avoided, and how many have been committed, in different types of plan. It is here, that we shall see the vast superiority of generated plans. They avoid mistakes. A fabricated plan cannot avoid mistakes, and in all fabricated plans, the overwhelming majority of possible mistakes, are actually committed.

6 / THE SIGNIFICANCE OF GENERATED STRUCTURE

The significance of generated structure lies in the concept of mistakes. Fabricated plans *always* have many mistakes — not just a few mistakes but tens of thousands, even millions of mistakes. It is the mistake-ridden character of the plans which marks them as fabricated — and that comes from the way they are actually generated, or made, in time. Generated plans have *few* mistakes.

In order to describe what it is that actually happens in time in the case of a generated structure, I shall draw attention to the vital point. Let us consider D, one of the fabricated designs, and compare it with the more organic design of C. We can see that at any given place in C, many small things work. The house has a nice street outside: The house across is in a good relation to it; the space opens out to a place where children can play. The house has a front which is recognizable. Each place has its own uniqueness.

A dramatic way of expressing this idea is to say that by comparison in the fabricated scheme E (which has about 400 houses), each element has the potential for a number of mistakes. Let us make a wild guess and say that the drawing E contains 400 houses, hence about 1600 elements (lines). I shall say (and argue) that in a mechanical scheme like E, each line has roughly five mistakes associated with it. By that I mean that the line was drawn on a drawing board, without any opportunity for the line to be modified, or adjusted, according to realistic perception of actual difficulties and opportunities on the place itself. I claim that in a professional planning/design/development process, this failure of adaptation is inevitable, and that at the time of its creation no process was put in place to remove these mistakes.

By contrast, in C (Shilnath), I argue that each line represents a decision that was put down, one at a time, over a history extended in time, and that each decision was made by people associated with the place, the house, the immediate conditions. As a result of this relatively slower unfolding process, and as a result of the decentralization of the decision-process in different people's hands and in the hands of people intimately associated with the needs of the situation, I shall say, further, that at the time the line is put down, each of the five possible mistakes (that existed in E) is here corrected, by adaptation, and that as a result of the process which allows each line to be considered carefully, and adjusted, these five possible mistakes are eliminated.

The upshot of this comparison suggests that the plan E must inevitably have some 8,000 mistakes in it. There was, in the procedure used to generate this plan, no way to avoid it. Any process which statically determines these elements (lines, edges, and positions) merely by drawing-board planning, cannot avoid having some 8,000 mistakes.

C, on the other hand, has very few mistakes in it — or perhaps, by the same kind of count, at most a few hundred. Thus, the effect of allowing C to grow in time, and to grow gradually, to unfold gradually, is that most of the possible mistakes in it are eliminated, while a designed and planned object such as D will have on the order of 10^4 mistakes in the site plan alone.

That is the enormous difference between a generated thing, and a designed and fabricated thing. In a fabricated/designed thing, it is virtually certain that it will have a huge number of mistakes, reducing the value of the environment, and reducing its ability to support people's daily lives in an efficient and adequate fashion.

7 / A THOUSAND TRILLION POSSIBLE MISTAKES IN A HUMAN EMBRYO

If an embryo were shaped by fabrication, and not generated, the number of mistakes would be unbelievably large.

The human embryo is created by 50 doublings of the cells. Starting with a single cell (the fertilized egg), after 50 doublings, the embryo has 2^{50} cells. During this doubling process that occurs 50 times, each cell has the opportunity to adapt itself, and to remove possible mistakes by position, adaptation, pushing and pulling. The total number of opportunities for correction, then, in the growing embryo, is $(1+2+2^2+2^3+....2^{50}) = 2^{51}$. Reversing the argument, we may express this by saying that the assembly of embryo cells, if not given the chance for adaptation and if instead made by design or fabrication, would typically have 2^{51} mistakes — a truly enormous number, roughly 10^{15}, or a thousand trillion possible mistakes. That is what would happen if an embryo were designed and built, not generated. If an embryo were built from a blueprint of a design, not generated by an adaptive process, there would inevitably be one thousand trillion mistakes. Because of its history as a generated structure, there are virtually none.

8 / ONE MILLION POSSIBLE MISTAKES IN A COMMUNITY

The number of potential mistakes avoided in the settlement of houses in Shilnath is certainly far less than those avoided in the human embryo. But the principle is the same. In any site plan for a few hundred houses, like the examples D and E and F, there will inevitably be on the order of ten thousand mistakes.

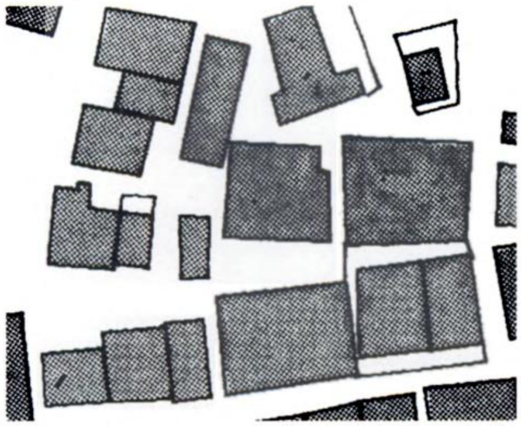
I have estimated, above, that the possible mistakes in a plan for 150 houses, will be about 1000. That is for the site plan alone, only for the *boundaries* of the buildings. In addition, in the type of planned architecture typical of public housing, or development tracts, we have the further possibility of similar huge numbers of errors in each individual house. As we see in the calculation on pages 192, each house, itself, then contains the possibility of some additional 5,000 mistakes per house. If there are 150 houses in a small community, we then have the possibility of approximately (1,000 (for the siteplan) plus 150 times 5,000 (for the houses)) or some one million total possible mistakes in the project as a whole — an egregiously large number. Unfortunately this is not fanciful, but a fact about the way we design and build our houses today.

If we have responsibility for such a plan, or for building such a community, we can only avoid the huge number of inevitable mistakes, by finding some way to make the thing a generated structure, not a fabricated one. This requires deep — very, very deep — changes in procedure.

9 / THE COMPLEXITY THAT WAS GENERATED IN SHILNATH

The primary way in which complexity of structure reveals itself, is in the internal density of significant relationships which exist. When adaptation occurs successfully, and each line or element created is created in such a way as to avoid its possible mistakes, it does this by creating meaningful relationships in every direction.

Let us once again look at Shilnath, and examine the particular part of it which is shown below in the detailed plan (page 189) blown up to a large scale. Please look at the one small house which is freestanding in the middle of the space shown on the left. This house performs several functions at the same time. First, it is placed in such a way as to close the space to the right. Thus, it makes that space somewhat more private, creates a natural boundary to it, yet leaves it half open to movement and view. We should be aware that this subtle "closing while yet leaving open"



A detail of the settlement at Shilnath. Here we see the profound complexity of overlapping relationships that is typical in every generated structure.

is a human practical matter that concerns the feelings of the people living there, their daily experience, and is something that was plainly done by them to satisfy the way they conduct themselves socially, and emotionally, in their normal daily lives.

Looking again at the small house, with reference now to the long axis it creates, we also see that it is placed to have a relationship with the long house that is above it (on the drawing) and with which it is nearly coaxial. This creates a sense of cooperation and connectedness between these two long houses, and it makes the face of one house face directly to the other. The specific deliberateness with which this is done tells us that once again, it has practical human reasons. Further, the connectedness between the two houses is embodied in the beautifully shaped squarish open space between the two. Again, we see that the makers of these two houses placed their buildings to shape a comfortable space of a certain dimension, which is comfortable for play, conversation, and other things.

We know, too, that the small house, being surrounded by the street, has the capacity to function as a fulcrum at a time of festival, since it allow processions, or dancing, to move around and around the house, without stopping, a common way that people move during marriage festivals and other more informal celebrations. Furthermore, our small house also has an important relationship with the narrow path below it (in the drawing). Also it forms a square space just below it, at the opening to that path. And then, finally, the house also forms an important part of the space on the left (in the drawing), where it helps to shape the end of that space by narrowing it down and forming and endpoint. In this regard the front of our freestanding house also has a significant relation with the fronts of three or four houses to its left (above the forementioned space), by forming a wall, or a facade, or edge of the space, when taken together with these houses.

Our small house thus enters into at least seven meaningful relationships, overlapping and connected. Each of these relationships is embodied as a center, and these seven centers are strong and living ones. Further, the relationships are motivated by practical daily-life concerns, which come from people's most ordinary strivings and needs and wishes. They are not esoteric artistic efforts to create nice space, as a western artist might attempt: Rather they are very mundane, sensible, and practical expressions of real thoughts, feelings, emotions, actions, games, commerce, and neighborly behavior. They are above all down to earth.

Every one of the 150 houses in the Shilnath community enters, in a similar fashion, into multiple overlapping relationships with other houses and other spaces. The subtlety of these relationships, and the connective tissue which they form, is a large part of the life in any living structure. Each of these relationships takes the form of a living center. Since the one example I have been discussing alone creates some seven vitally important living centers, as a result of the extreme carefulness of placing and position, size, and shape, we may surmise that the community as a whole probably contains some 7 x 150 or about a thousand overlapping living centers. This is the true complexity typical of any living structure, and as in this instance, such complexity can only be created when the structure is a generated one.

10 / IN INDIVIDUAL BUILDINGS, TOO, WE MAY ASK WHAT IS THE NATURE OF A "MISTAKE?"

The complexity which I have described in Shilnath and the other generated settlements can be seen, almost without change, in individual buildings, and in objects, too.

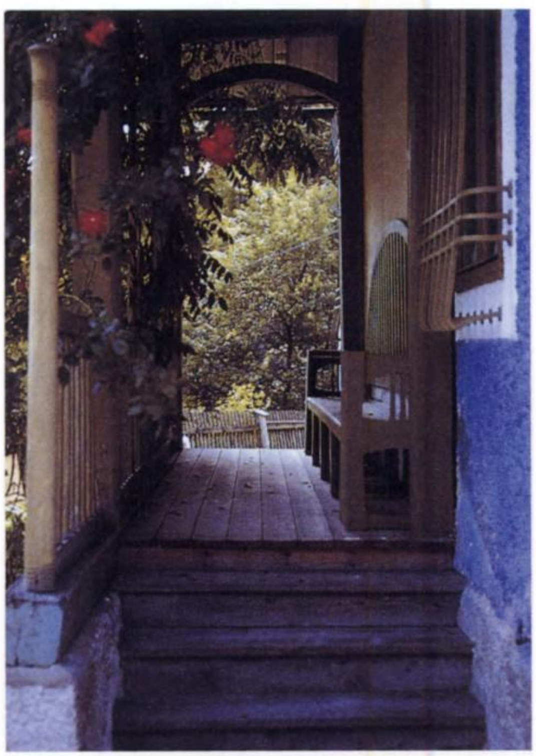
In each case, we have a structure in which the edges, spaces, positions, colors, either have — or do not have — the levels of subtle adaptation that I have described.

They have thousands of potential mistakes; and, when fabricated, most of these mistakes do actually occur *in fact*. If generated, there is a chance that these mistakes do not occur, and the object, or building, is harmonious in its existence in the world, and in relation to the things around it.

Whether the mistakes are successfully avoided, depends on the adequacy and subtlety, of the generating process. In particular, it is essential — absolutely essential — that the adaptation, and the avoiding of mistakes, occurs at several levels of scale, as I described earlier. If this does work, then the adaptation is capable of real, subtle fine tuning. If the adaptation occurs only at one level — what I might call, well-meaning tinkering — this will not work out very well.

Let us consider the kinds of things which are, in my definition, "mistakes."

A window sill may be just right to put thing on — or it may be too small. A window may look at a favorite tree, or it may be placed to look at a wall. The bath maybe built so that one hardly has place to put the soap; or it may be built with a comfortable shelf where soap and shampoo can be without falling off. The light in a room may



Few mistakes: Generated structure of the front part of a house which HAS been generated

Many mistakes: Fabricated structure of the front part of a house in a housing tract which has NOT been generated be placed to create a comfortable atmosphere at night, small pools of light in just the right places, or it may be merely a light fixture wherever the builder put it. The garage can be a box, barely big enough, or it can have a shelf, or bench, with tools, with a small but adequate window above the work surface. A stair post is either just in the place where your hand comes down as you walk down the stair or not. A paving which warms your feet or your body, because it is colored or terracotta to be absorbent and therefore gets warmed by the sun, works. It is well-adapted to need because of specific small, features that it has.

Each of these things, once again, depends on adjustment, attention to position, dimension, comfort, and adequacy. If missing, they are mistakes of adaptation — adaptations that were not achieved.

Look at the steps of the blue porch, on the left-hand page. It is full of subtle adaptations: the seat up on the right, the railing on the left, the 'wrong' top riser, the boards on the deck, the arched opening framing the trees beyond, and the special choice of paint color giving the trees their special luster. Each one of these is coupled with a careful adaptation that makes life more worthwhile, more practical, without disturbing the harmonious character of the place. But in the porch in the right-hand picture, from a Fort Lauderdale housing tract, the adaptations are missing. Instead of sizes chosen to work right, dimensions are based on cheap cuts made on a 4 x 8 foot sheet of plywood. Windows are standard and cannot be fitted to frame a view or to be just the right size for the feeling of a room or of a view. The height of the ugly slot in the front is done without careful regard for a person entering a house, or, of course, for the concern and special nature of any one particular human being who is to love or cherish this place. The lack of adaptation in the one building, and the fullness and subtlety of adaptation in the other, are clear.

In the next section, we shall see just how many of these adaptations, and how many mistakes, are typical in an ordinary house. The number is surprising. And in the foregoing argument, it is vital to understand that the beautiful blue porch is not good because it is archaic. Some people might respond to the example by saying, "Well, this beautiful porch is all very well, but it is nostalgic, just something from the past." The point, of course, is not that the porch is ancient or archaic, but simply that it is *better.* It has the deeper adaptation, to its use, to its surroundings, and to its internal orgamization — and is *therefore better.*

Above all the blue porch avoids the two-thousand mistakes which are potentially present in such a porch, and for this very concrete reason is a better, more deeply adapted structure. The battle cry of modern architects, throughout much of the 20th century, which branded such things as nostalgic, irrelevant, not modern, and so forth, was really little more than a wild attempt to justify the huge mistakes modern buildings (and developers and architects) were making daily, by claiming that things which did not make these mistakes were "bad" and "nostalgic."

In fact, of course, the number of mistakes or its contrary — depth of adaptation — has nothing to do with style. In the 20th century, for instance, one of the classes of artifacts which frequently had very good adaptation, were the motorbikes made and adapted by bikers for themselves. Here there was nothing nostalgic at all — merely a community of people with good access to machine tools, welding torches, and a strong desire to make their bikes good for themselves. Long-haul truckers had a similar (not quite so intense) love affair with the cabs of their long-haul rigs, which they also frequently tuned to their own needs, and where once again people managed frequently to reach a relatively mistake-free environment. No nostalgia there!

Nearly all the beautiful and living structures described in Book 1 are, on close examination, generated structures which have precisely this many-level adaptation and overcoming of possible mistakes deep in their fabric, because they were made by processes which *generated* — not fabricated — the structure.

11 / THE FIVE-THOUSAND POSSIBLE MISTAKES IN A TYPICAL HOUSE

H many possible mistakes are there in a typical house?

In order to estimate the number of potential mistakes which can occur in a typical house, it is helpful to consider the fact that a typical house nowadays has about 2000 man-hours of labor in it. During an hour, decisions of dimension and position are being made by a carpenter several times an hour; thus, we have a likely guess that the house contains some 5,000 decision points — each one, again, capable of being done right, or being a mistake, or being done right.

It is fair to say that if any one of these decisions is made blindly, according to design information in a construction blueprint, it is virtually certain that this decision will be a mistake since there is — in general — no way that luck could manage to make the decision come out right. The mistake will be avoided, and the "right" thing done, only if the decision has attention, thought, and mental effort.

Consider the number of physical pieces of material in a typical house: steps, sills, walls, baseboards, floorboards, tiles, shelves, doors, windows . . . A reasonable guess is that there are likely to be a few hundred really important pieces of material of this kind. With each piece there are decisions about position, length, breadth, height, relation to the next thing, extension, connection — again half a dozen or a dozen. All in all, by this method, too, we arrive at a likely number of about 5,000 decisions that can potentially be wrongly placed, and will, inevitably be wrongly placed if they are not given special attention while the house is being made.

It must be said emphatically that this by no means requires an increase in construction cost. The valuable *decision time* need not be done by a highly paid worker — it can be done by family members themselves, provided what they decide can then be built without extra effort or material cost, and the only thing the construction worker or craftsman must do then is to cut, nail, and place material correctly, according to the wishes of the client. This does of course require new forms of contract which provide new relation-

Generated structure: here the wishes of the family, their comfort, and the adaptation of use to structure have been simply carried out, without fuss, all quite direct. Contrast this with the photograph on page 184. Note: this picture is not about "Isn't poverty wonderful." It is about the fact that even with very simple means, people can make themselves comfortable when permitted to do so.

A room (my own library) in which a very large number of adaptive decisions (about 1000) were made, in a relatively short time, and at very low cost. Nevertheless it is a truly generated structure, because every decision, no matter how small, was made in such a way that the resulting relationships became meaningful.

ships between client, craft and labor, and new forms of cost control which can achieve these things in a practical legal framework. The topic is taken up more fully in Book 3.

An example of such a process, where low-cost decisions having a direct bearing on the comfort and harmony of a room, were made in a short space of time (about one week) is presented elsewhere (pages 387–90). An example of its results are shown in the photograph above.

It is also necessary to recognize that the generated character of elements, in a house or anywhere, goes down to the smallest details. Consider, for example, the Japanese tea bowl and the wine glass, shown on the next page.

The concept of mistakes does not only apply to what is functional in the obvious way. A mistake, is ultimately a geometrical problem, which bears on what we call function, and the concept of practical function is only the tip of the iceberg. This matter is fully discussed in Book 1, chapter 11. So, in a small object which appears in the house, within its structure, even within an inch or two, there are also mistakes possible, or harmonies achievable. Let us examine the wine glass and the tea bowl. We may imagine, in each case, that as the object unfolded, centers were latent, and these centers, at the next step were embellished or not, opportunities created by latent centers pressed forward, or left dangling.

In the wine glass we see a number of mistakes. The top of the glass edge of the bowl — not very comfortable for the lips — could have been made rounder; as a boundary, then, it would have had a certain fatness or juiciness, which has not been pursued. The stem of the glass, where it meets the base, is flaccid, and this junction, as a center could have been more beautifully shaped.

But in the Japanese tea bowl, we see such centers have been taken to the fullest, and each latent center, at the time of its making and con-

A famous Japanese tea bowl which, in spite of its appearance of having been "designed," is actually a generated structure—hence its beauty.

*A "fabricated" object—a glass made in the Royal **Dutch** Glassworks, well-designed (perhaps), but utterly dead as an object—because it has no generated structure.*

ceiving, pressed home to become a structure of beauty. Of course, when we talk about such intense attention to small details, this is not something that could be carried out in every part of the house, in every domestic utensil, every stair rail. But here, too, thousands upon thousands of mistakes can be made—and *are* made daily in such common objects as the wine glass. They add to the sum-total lack of harmony in the evolving whole. But when taken seriously, even if it is only here and there, in one object such as the tea bowl, or in one special window, the house will gain enormously.

The bowl, in regard to its shape, its glazes, its decoration, the form of the emblem drawn on its surface—all of them are *generated.* At every level the bowl is a generated structure, through and through. By comparison, the wine glass shown above next to the tea bowl, and made by Royal Dutch Glassworks, is stiff and lifeless. It is *not* a generated structure. This is reflected in the fact that the wine glass has not been thought through for comfort. For example the stem is thin, one feels that it is necessary to pick the glass up by the stem—yet this is awkward. The bowl of the glass is not comfortably shaped for the hand. The Japanese tea bowl, on the other hand, is very comfortable to hold. It is made for two hands. the cup is raised from the table, so that one's fingers fit underneath easily. And the slight, yet extraordinarily subtle curve of the bowl is designed to be comfortable and comforting as the hands go round it.

Let us ask why the tea bowl is so much more "generated" than the crystal wine glass? Why is the glass stiff and lifeless—harsh—while the cup is unified and harmonious—orderly, yet soft? We do see, of course, that the tea bowl is replete with the fifteen properties, as explained already in Book 1, chapter 5. But why does this geometrical quality, as it appears in the tea bowl, come necessarily from the history of this object unfolding in time?

Let me ask this more clearly. In the tea bowl, we see many centers, strong centers, levels of scale, massive boundaries, good shape, deep interlock, and so on. All the fifteen properties are there. And they are largely missing from the wine glass. But what does this have to do with time? What was it that made this structure of centers achievable in the tea bowl?

The answer is complex, and lies at the core of the transformations I shall discuss in chapter 7, but in a nutshell the answer is this: If you want to get a system of centers to appear in that cup or glass, you must introduce them in a certain order, the placing of each depending on infinitesimal subtleties in the structure and geometry, as they have appeared up to that moment. This is what the loose term "unfolding" means. And further, you can only get this structure by allowing the profound and multiple structure of centers to appear in a certain order, so that you get each bit of the structure by unfolding it — *from* the previous state. Thus the importance of time, is not merely that you have a chance of tinkering and adapting. It also allows you to get each next layer of structure from the previously established layers of structure. Complex, generated structure *cannot be arrived at in any other way.* One structure is established. The next structure is then made to appear within that structure, and *from* that structure. Each stage develops from the previous stage, each one creating the conditions from which the next can be created, and from which it flows. It is in this process that the fifteen properties, and their enormous density, can be achieved. *That is the secret of the whole thing.*

12 / THE SOCIAL AND MONETARY COST OF THE ONE MILLION MISTAKES IN A FABRICATED COMMUNITY

In order to arrive at an estimate of economic damage, we need to find a decisive way of evaluating the importance of generated structures, by making a cost analysis of the mistakes.

The very large number of mistakes which follow inevitably from constructing buildings as non-generated structures is very large indeed. These mistakes are embarrassing, uncomfortable, often ugly. They reduce life in our communities, and fail to support people's lives effectively.

However, the poor environment and the countless inevitable mistakes of adaptation might elicit no more than a few tut tuts from planners or architects or public officials. But the truly dramatic consequence, the devastating impact of these mistakes on our society is not made sufficiently visible by referring merely to these social and psychological discomforts.

What has to be said, is that the whole system of these mistakes, and the way we keep on introducing them into the built world, *is also very costly.* It is exorbitant in cost, and imposes massive economic burdens on society.

Indeed, when we calculate the negative economic effect of fabricated structure, we shall see massive impact in concrete money and fiscal terms, so massive that the sheer number of mistakes must be capable of communicating with the politicians and business leaders of our era.

COST ANALYSIS FOR A SINGLE HOUSE

The mistakes I have referred to are indeed very very costly. I estimate that an ordinary American house contains a density of about 1 decision per cubic foot. That means that a house of 2500 square feet is likely to contain about 20,000 possible mistakes, when the house is *not* generated.

For the library shown on page 193, decisions were made at the rate of about 10 per hour, for twelve days, thus about 1000 decisions in all, in a room 10 feet by 14 feet by 8 feet 6 inches high — about 1200 cubic feet. This yields a potential-mistake density of nearly one potential mistake per cubic foot. The bookshelves are ranged in size, corners are made with special cuts, colors and trim are carefully chosen, each cabinet door, chamfer, and division between shelves, and spacing of dividers, was chosen to increase the function and usefulness of the room. The details of the library are described more fully on pages 387–90.

Although any one of the mistakes by itself is not strongly noticeable, still, the presence of mistakes add up rapidly, and their *absence* controls the monetary value of a building. If the windows are nicely proportioned, the house becomes more expensive. If the window sills are good, the windows, and the rooms are worth a little more. If the windows look towards beautiful views (a function of the window placement, not only of the potential for view that is inherent in the land), the house is worth a lot more money, often as much as $20–30,000 more. If there is a beautifully placed, and cared-for tree, growing by the front door, the house may be worth $10–20,000 more than it would be worth if that tree were not there.

Some mistakes are more costly than others. If the baseboard where the wall meets the floor, is cheap or badly made or badly proportioned, the room is likely to be worth, on the average, $100 dollars less, and the house, altogether, is probably worth $500 less. Here the mistake-cost is about $1 per running foot of baseboard, similar to the figure of $1 per cubic foot for the room. If the view is badly chosen, or the tree by the front door is badly handled, the cost is much higher, on occasion it might even be as high as $5,000 per cubic foot for a few cubic feet.

It is difficult to get a reliable average cost figure for mistakes, but, just as a start, we may contemplate the mistake-costs as lying in the realm of $5–10 per cubic foot, thus potentially as high as $200,000 for a single American house of average size. And, indeed, this is a reasonable number, even though it seems outlandish. The cost of a house which has no mistakes in it, a normal house, in which every detail is perfectly adapted — commonplace at some 'antique' periods of history, but a rarity today — can easily run to the order of $750,000. The difference in value between a house worth $150,000 (which contains 10,000 mistakes) and the same sized house, containing no mistakes (which would be worth, say, $600,000 since it is a rarity today because houses nowadays are so rarely *generated*), might easily be in the range of $450,000 (if such a house were ever to be available at all among the available stock of newly built houses).

In passing, it must also be mentioned that good adaptation is not the prerogative of the rich. In fact it has relatively little to do with the cost level of the house or the income level of the household. In the Indian houses from the communities I have cited earlier in the chapter, total cost of a house may be no more than $3,000 ($US, 1999). And the houses are smaller, say 600 square feet, thus containing only about 5,000 potential mistakes. Yet a small house with the amenity, comfort, charm, and physical rightness which occurs after 5,000 successful adaptations in a proper unfolding, is likely, even in India, to be sought after because it has become so rare, and might well be worth $30,000. Regardless of absolute level of cost, the difference in value between a house which has 5,000 mistakes of adaptation, and one which has none, is like to be on the order of a tenfold difference, no matter what the absolute value of the house may be.

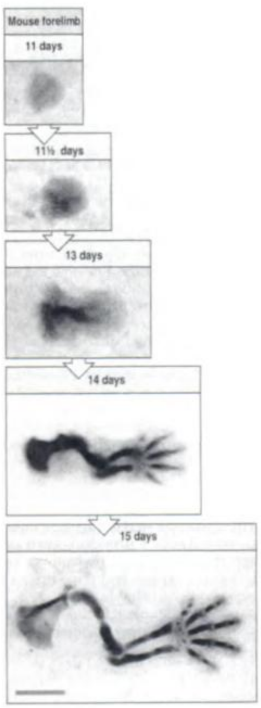
COST ANALYSIS FOR A COMMUNITY OF HOUSES

In the low-cost Indian example, if we use the assumption that house value doubles from $3000 to $6000 when the houses are mistake-free, the loss of value for a community of 150 "fabricated" houses would be $450,000. Using a more accurate guess of $2 per mistake and 5000 mistakes per house, the mistake-cost in a community of 150 fabricated houses would be $1,500,000: a fortune for low-cost housing.

If a community of middle-class American houses has 150 houses in it, the total loss of value in the developer-designed scheme with 20,000 mistakes per house, would be 3 million mistakes, or, at $10 per mistake, on the order of a staggering $30 million of lost value for the community.

13 / DIFFERENTIATION

Needless to say, the highly complex million-fold adaptation of elements cannot occur in random order, or by mere trial and error, nor can it occur successfully through addition, one element at a time. Merely additive processes (like the assembly of an erector set from fixed components that are arranged and rearranged) never lead to complex adaptation, or to profound complex structure.



Differentiation in a growing embryo. The unfolding foot of a mouse between the 11th and the 15th day.

The key to complex adaptation in a generated structure lies in the concept of differentiation. This is a process of dividing and differentiating a whole to get the parts, rather than adding parts together to *get* a whole.

In a structure which is differentiated, the structure will not, in general, be made by small piecemeal acts happening in random order. Rather, each step creates the context for the next step in the whole, and allows the process as a whole to lay down, next, what has to be laid down next in order for an orderly unfolding to occur, and to allow a simple and coherent form to arise in which, nevertheless, all the important small details are done just right.

In chapter 7, we shall see an outline of such a differentiating process, and I shall provide a template for a process that I call the fundamental differentiating process, present in all adaptive differentiation. The fundamental process, when present in specific social processes, is capable of generating living structure in buildings and communities. It is, in principle, the key to the effective creation of generated structure in all built form. We shall see how the repeated application of the fundamental process allows large elements to be differentiated to generate smaller elements in such a way that careful, mistake-free adaptation of all elements, at all levels of scale, in the built world can, in principle, be virtually guaranteed.

14 / CREATING HIGHLY COMPLEX OBJECTS

In general, we may say that a complex object will only be successful if it is generated. This is obvious in the case of organisms (animals and plants), which are always generated. But it is less obvious, and so far hardly recognized at all for the complex objects we create such as houses, buildings, rooms, cities, and neighborhoods.

Let us consider the case of software. A typical computer program contains tens of thousands of lines of code; others in daily use contain a million lines, even as many as ten million lines of code.

In recent years some attention has been given to their theory of design, and some improvements have been made in contemporary ways of thinking about their design. Computer scientists have told me proudly that they consider computer programs the most complex objects designed by human beings.

Yet, to date, there is little recognition of the following commonsense point: If indeed the programs are so complex, then it is likely that they, too, will be potentially subject to hundreds of thousands, perhaps millions of egregious mistakes of adaptation. Here I am not only talking about "bugs" — failures which stop a program from running altogether. I am talking about mistakes of adaptation, ways in which the program fails to do what it is supposed to do, fails to meet the needs of the people who use it, or is more awkward, more annoying, less useful, than it is supposed to be. If the analysis given in this chapter is correct, then it is fair to say that truly successful programs can only be *generated*; and that the way forward in the next decades, towards programs with highly adapted human performance, will be through programs which are generated through unfolding, in some fashion comparable to what I have described for buildings.

This chapter was first composed as a lecture to the computer science department at Stanford University. After the lecture, I had a chance to hear comments from many of the computer scientists in the audience. Much of the commentary I heard went something along these lines: "This is really interesting. . . perhaps you should call it 'evolutionary adaptation' instead of 'generated structures' " and "We computer scientists ourselves often practice various form of evolutionary adaptation in software design. Good software grows, by steps with feedback and evolution, to something better . . ." And so on.

The essence of all these comments was what I call gradualism. It says "Yes of course, in the case of a complex structure, we cannot hope to get it right first time around, so we build it, run it, test it, fix it, change it . . . and keep on doing this so that it gets better." What has become known as *Extreme programming* is a way of doing this for software development, with a very short cycle of evolution and adaptation, repeated many times.[2]

Of course I am in favor of small steps, of adaptation through trial and error, and of what we may call evolutionary adaptation (see chapter 8). But this is not the central point at all. After listening to all these computer scientists' comments, and taking them to heart, I realized that I had failed, in my lecture, to emphasize the real essence of all generated structures. *The real essence lies in the structure-preserving transformations which move the structure forward through time, and which are primarily responsible for the success of the generating process.* The needed transformations are not merely trial-and-error steps, or some neat way of continually checking and making things better. In chapter 2, I have referred to the fifteen transformations which act, in all structure-preserving transformations, to move a whole structure forward in a deliberate and explainable way. *It is because of these fifteen transformations and their effect*, that a whole may be said to "unfold." It is because of these transformations that a whole becomes coherent, and beautiful. And it is because of this unfolding, and the way the unfolding processes work, that the structure is able to become "mistake-free."

To assume that the point of generated structures is merely slow, step-by-step evolutionary adaptation, is to make the same mistake that early adherents of Darwinism made in biology — to assume that small steps *alone*, modification coupled with selective pressure, would be sufficient to get a genotype to a new state, hence to create entirely new organisms... and so on. This does not work, and is now widely recognized not to work, because it lays too little emphasis on the (hitherto) unknown transformations which actually do the hard work of moving the evolving organism through stages that lead to its coherence and its geometric beauty in the emerging genotype (see chapter 1, pages 42–48)

15 / THE GREEK MARBLE HORSE

Highest example of generated complexity: Greek carving of a horse, 6th century B.C. *Look at the eyes, the head, the forehead ornament, the strap around the nose — each part has been transformed, by transformations originating in the whole, to have* POSITIVE SPACE *and* GOOD SHAPE *which thus intensify the whole.*

What I mean by a generated structure is just such a thing. It is a mistake-free structure which is beautiful and coherent, and which has become beautiful and coherent because of the impact of successive applications of the fifteen transformations which create, bring out, and generate its beauty and its elegance of structure.

The beauty of the generated object, and the connection of this beauty to the mistake-free nature of the generated object, though alluded to in discussion of the Shilnath plan (page 182), is not obvious. Yet this connection, surprising though it is, is very much the essence of all that follows in the next eleven chapters. It may be made vividly clear, by discussion of an ancient Greek carving of a horse.

Look at the marble horse shown here. Let us consider carefully, what the artist did to make this marble horse, and how the fifteen transformations helped him, and how the mistake-free nature of the carving, and its great geometric beauty, are really aspects of one and the same thing. The artist had, one assumes, seen many horses. His carving is a distillation of what he knew. And how was his structural knowledge distilled in this carving? Let us look at a small part of the horse — for instance the place on the nose, where the straps go across the nose. If we look at the sculpture, we see how each piece — the nose, the space of the nose, its curve, the lay of the strap, the shape of the strap, its particular bulge, the space between the two parts of the strap — these are all positive. They are positive, too, in a real living horse. But a typical "realistic" painting of a horse is different. There, typically, these portions are not living centers with positive good shape, but are much more loosely shaped; all in all there is typically a kind of fuzz of unshaped inarticulate space, lying on the nose, between the eyes, the straps themselves are less beautifully formed. All these fuzzy bits are *mistakes.* To get rid of these mistakes, the individual shapes of space and objects must be made more solid, more clear — and the elements which are fuzzy, vague, must just be cleaned out altogether to leave the rest coherent.

Look at a more complex example. The eye of a horse is a mysterious structure, not easy to capture. It bulges, is visible from the front, yet somehow sits in the side of the head, under the occipital ridge. If you try to make these features literally, the bulging eyeball and the crest bone, you may very easily fail to see the whole in its deepest way. Trivial realist artists often make this kind of mistake. But the ancient Greek sculptor who made this marble horse looked at the wholeness of the eye in a real horse, and saw the way that the eye in the real horse causes a field effect. To create a representation of the *wholeness* — not merely of the details — the artist applied some of the structure-preserving transformations. He used the ALTERNATING-REPETITION, BOUNDARIES, and STRONG-CENTER transformations, to create a large-scale field effect extending all over the side and front of the horse's head, just as it does in life. To do this, he had to invent something which looks to a modern eye, abstract and unlike a real horse. The lines visible around the eye of the sculpture do not appear in a real horse. Yet in fact the marble horse is more deeply horse-like, has more of the real feeling and presence of a horse than most of our contemporary "realistic" representations, because it is the *wholeness* and its true field of centers which finally appears in the stone, not merely an accurate transcription of details. And the same thing occurs throughout this sculpture. Again and again, we see living centers in the carving: the nostrils, the nose leather, the plate between the ears and on the forehead, The fifteen transformations create beautifully organized positive space in these centers, in a nearly ornamental fashion, throughout the fabric of the head.

This is all highly relevant to our understanding of generated structure, in the following way: What the artist did is roughly what nature does, when structure-preserving transformations preserve and extend the wholeness of a given system. More important, in *any* human-made generated structure, the fifteen transformations must be brought in, in an equivalent fashion, to create the link between the larger whole, and the detailed forms within it.

It is this transformative process which allows a generated structure to become alive and mistake-free — this which allows a living process to generate truly living forms.

16 / CONCLUSION OF THE DISCUSSION ON GENERATED COMPLEXITY AND PREFACE TO CHAPTERS 7-17

So, now, pulling together examples and discussions, can we understand what it means to "generate" a structure?

The argument put forward is that the high level of complexity we need in urban tissue, working and dwelling spaces, computer programs, etc., can only be attained when an existing, albeit latent, structure unfolds through differentiation to the needed level of complexity. Each differentiation, i.e. decision, is made in sequence and in context. It is reworked right then and there until it is mistake-free, i.e. , it takes into account all the connecting relationships. This must be done in sequence and in context because the necessary information for a successful decision is not available prior to that step in the unfolding.

This differentiating process is a successive application of the fifteen structure-preserving transformations that both adapt each part to the whole, locally, and, at the same time, preserve and bring forth the deep geometric structure of the larger surrounding whole. It is important to grasp that each differentiation *adds relationships and brings more interdependence among the centers.* Of course, as a result of the many adaptations, and the growing centers and properties, the structure slowly becomes thick with relationships. It is getting denser and denser all the time. And it is vital, for success, that the process is *able* to keep on cramming in more and more relationships, so that the mistake-avoiding adaptations can continue to be generated.

This "cramming" of complexity brings with it a need to constantly clean out any non-functionalities and leave only the most simple possible geometry in place. It is simple structure that allows for maximum relationships (you need only think of the sphere whose simplicity allows for so many properties at once).[3] The transformations called SIMPLICITY, INNER-CALM, and THE-VOID have as a direct function the task of keeping a structure clean of useless debris and open to the possibility of further useful differentiations.

In short, then, to make room for more and more relationships, there is a cleaning process going on in parallel with the differentiating process. The process keeps cleaning itself out. Any garbage that accumulates has to be flushed out. The process is simplifying itself, getting rid of debris, and leaving itself, at each moment, with the cleanest and most spare structure possible. Only then, can the system be certain that there will always be room for more relationships, and only then will it truly be possible to keep injecting further transformations and maintain a coherent structure. It is this simplifying process, together with the fifteen transformations, which makes the beauty and majestic structure we think of as deep primitive art, or nature generating nature, at its best. Please look at the horse in this way.

A generated structure seeks to maintain and enhance its own internal geometric coherence, to avoid mistakes, and to be open to evolution and differentiation. We can admire Mother Nature generating the deeply beautiful simplicity and complexity of the daffodil is just this way. In fact, there is no other way. Alas, since we are not Mother Nature, when we generate our towns, computer programs, or attempt great art, we have to sweat it out with intense attention to what we are doing.

So now we have a rounded view of what a generated structure is. The structure seeks, above all, to avoid mistakes. To do it, it promotes an activity of structure-preserving transformations, to maintain coherence. In addition, to make the structure capable of containing the vast density of significant relationships which eventually builds up, the process is also cleaning the structure and simplifying itself continually, at the very same time that complexity is building up.[4] To do this, the leveling and sharpening that is typical of a process trying to preserve relationships, and get rid of non-relationship stuff, so that a spruce, spare structure is being built, and we keep moving towards the fine, profound simplicity which is typical of the greatest art, and typical in nature. This is the only way a profound, well adapted structure can be built.

In the next eleven chapters, 7–17, I shall lay out some of the more important aspects of all living process, which allow a process to embody these concepts and tools, and which provide the core of a theory which shows us how living structure may be generated. The emphasis, throughout, is on the creation and generation of beautiful wholes, made to play their proper part in the great whole.

NOTES

1. The examples of plans on pages 182–85 are taken from a housing study by Witold Rybczynski et al. HOW THE OTHER HALF BUILDS (Toronto: McGill University, Housing Publications, volume No. 9, December 1984.

2. See Kent Beck and Ward Cunningham, http://www.armaties.com/extreme.htm.

3. David Hilbert and Stephan Cohn-Vossen, GEOMETRY & THE IMAGINATION (New York: Chelsea, 1952), "The Eleven Properties of the Sphere," p. 215.

4. Precursors to this kind of thinking can be found in Christopher Alexander, "The Origin of Creative Power in Children," BRITISH JOURNAL OF AESTHETICS, Vol. 3, No. 2, July, 1962, pp. 207-226, where the boiling down of spatial relationships in order to create more coherent forms, is discussed as a feature of children's cognitive development. A PATTERN LANGUAGE also discusses the spatial richness and simplicity that emerges when numerous patterns overlap.