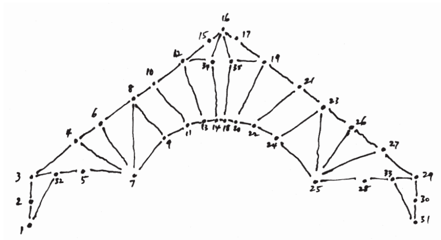


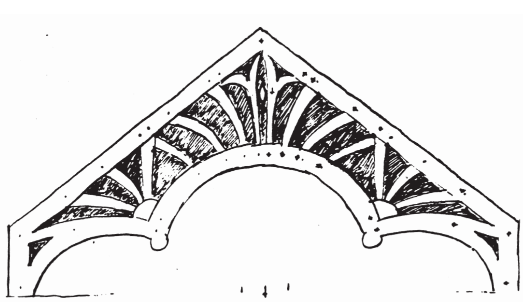
20. The tension arch

will be that defined by the configuration of the reinforcing bars, not that defined by the concrete. But the stiffness of the members considered as a configuration of rebars is often less than 20% of the stiffness of the full concrete section. There was a possibility, then, that the overall behavior of the truss might change drastically for the worse if we made this replacement, or might even collapse entirely. To check this worrying point Gary and I decided to try a finite element analysis in which all tension members would be given their steel stiffness, not the concrete stiffness.

The results of this analysis were fascinating. Instead of getting worse the behavior became *better*. All the shears in the top of the main arch went down to within acceptable limits. Better still the bending moments in the top chords also went down. And finally we noticed one more thing. In this modified truss the forces in several struts changed from compression to tension.

We now realized that as a whole the modified truss was working in an entirely unexpected way. The arch and struts were all together, working as a kind of tension network which resists the spreading of the rafter beams.

This was a highly unusual design, previously unknown to either of us. The three-arch arrangement which originally arose in response to the spatial configuration of the dining hall had finally been resolved in a form where this particular shape draws its structural strength from a novel way of working through a tension network arch. The oddity of the original configuration, caused by centers in the dining hall, had become a virtue in an entirely new structural design.



My original sketch of the final truss design

10 / EACH STEP USES THE FUNDAMENTAL PROCESS TO UNFOLD AN EARLIER WHOLENESS

At first sight, the various steps we took in the design of the San Jose truss seem very different from one another. In one step, to get the spacing of the trusses, we were looking at the windows to see if they have a beautiful shape. In another step we were looking at the distribution of tension and compression in the truss itself. In another we were concentrating on the shear force at three critical spots. In another, we were looking only at the beauty of the centers in the truss, to make it beautiful. In another we were looking at the thickness of the truss from the point of view of the steel bars crossing each other. In another, we were trying to find out how to make the formwork give us an offset between the inner members and the big members.

However, every single one of these steps, when interpreted correctly, was a structure-preserving transformation. And indeed, each of these structure preserving transformations was

The dining hall in the Julian Street Homeless Shelter, after the room was painted.
Christopher Alexander with Gary Black, Carl Lindberg, Avery Miller, James Maguire, 1988.

Trusses of the dining hall in their raw and most beautiful state, not long after completion.
Christopher Alexander with Gary Black, Carl Lindberg, Avery Miller, James Maguire, 1988.

Late evening sunset. The sun is shining on a cardboard model of a truss, full-sized, made to help us see if the truss looked right from below. I had a hunch it might not look right, and wanted to raise it. Our client was upset about the amount of time this would consume, slowing down the construction schedule. However, once the cardboard truss was above our heads, it was completely clear to everyone who saw it that it had to be raised by 18 inches to make the room look right. Even our client, concerned as he was about schedule, said, "I see now, that we have to do it." The astounding, 30-foot span, cardboard mockup was made by my student James Maguire and friends.

guided by one or another of the fifteen transformations described in Book 2 (especially chapters 2 and 7). Let me give a few examples.

Going from step 3 —> 4 we used ECHOES (reflecting the curved shape of the windows in the arch forms of the truss).

Going from 4 —> 5 we used LEVELS OF SCALE, GOOD SHAPE AND LOCAL SYMMETRIES.

Going from 8 —> 9 we used GOOD SHAPE.

Going from 9 —> 10, we used a simplifying process (INNER CALM) with strengthening of CENTERS.

Going from 12 —> 13 we used STRONG CENTERS and GOOD SHAPE to form the knobs.

Going from 13 —> 14 we used STRONG CENTERS and POSITIVE SPACE in the spaces between members to obtain the arrangement of plant like members going out at right angles to the curves of the arches.

Going from 17 —> 18 we used LOCAL SYMMETRIES, GOOD SHAPE to form the lily configuration.

Going from 18 —> 19 we used POSITIVE SPACE.

Going from 19 —> 20 we used ALTERNATING REPETITION.

Regardless of the particular structure-preserving transformation used, every step is some kind of structure-preserving transformation. Thus, each step uses the fundamental process, repeatedly. Instead of seeing twenty different steps in the process of designing this truss we may, more correctly, see twenty applications of the same step, over and over again.

At each step, progress is made using the transformations to intensify the field of centers reached previously. When the transformations alone were insufficient to guide me, I used the mirror-of-the-self as a more subtle criterion. Of course, the whole process was guided by practical analysis of structural forces. But even the forces themselves are seen as centers, and the process of elaborating and intensifying the field of centers was used to channel and redirect the forces themselves.

In some cases, it took a lot of effort, and trial and error, to find out which differentiation would do most to preserve the field and its centers. Various possibilities had to be examined and compared. But after hard work at each step it became possible to find out which of the alternatives that could be imagined preserved the wholeness most.

It is perhaps important to emphasize the novelty of the trusses which emerged from this process. In Book 2, I have stated that the fundamental process will produce a unique thing each time that it is used. This may be seen dramatically in the present case. Trusses had never before been built by this technique: They were shot with gunite, in the air. But what is more interesting is that this truss was completely new *as a structural configuration* — hence as a piece of engineering. A two-dimensional truss in which the tension, compression and bending are distributed in the bootstrap basket fashion we reached in this truss, was a completely new idea. It did not emerge from the intention or desire for a new idea. It followed just from the fact that the latent centers which existed in the wholeness of this emerging truss design were continuously respected and developed, step by step, while we watched what happened. Thus, what sounds like a conservative, dull process actually led to startling innovations.

The floral plant-like truss which came from this process followed naturally from the unfolding process. Yet it had never been seen before. Of course, two different individuals or groups, faced with the same problem, and taking the same steps, will not get the same result. Even if they find their way to one of the best half-dozen structure-preserving steps at each stage in the process, they will not choose the same ones, and the evolving designs will certainly diverge, in some cases dramatically, after only a few steps. So, of course, different engineers and architects will rarely go in the same direction. As a result, we get unique and beautiful works.

In our case the truss, its concrete, its shape, has a raw, gray, massive energy.

11 / APPROPRIATE STRUCTURAL ORDER FOR A LARGE APARTMENT BUILDING

We are committed to making each place, each room, window, floor, unique within the whole, according to its needs. How is this to be done in a large building?

Nearly all very large buildings are built with the assumption that each floor is structurally identical, and that the upper floors mirror, exactly, lower floors. Plan variation is usually achieved by arranging lightweight non-bearing partitions within the uniform structural grid.

In most 20th-century buildings such perfect floor-to-floor repetition was a fundamental feature of the design, and without this feature most 20th-century large building designs would not work structurally. In addition, the repetition lowers the cost of contract administration. But most important is the fact that it creates a workable structural design. The columns, beams and shear walls have vertical continuity thus making a well-behaved structure.

But exact repetition does fly in the face of the fundamental principle of unfolding. It requires that each part of a structure become that which is unique and appropriate to its position in the unfolding whole.

If we look for a new kind of large building, in which there is greater freedom from such floor-by-floor constraints, we are then virtually looking for a new order-type, a new kind of structural design which will permit each part of the building to fulfill its own nature, have its own appropriate character, without placing impossible demands on the structural design.

My colleagues and I worked out an example