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THE COUPLED PAN SPACE FRAME: A STRUCTURAL FRAMEWORK FOR SOLAR CONSERVING BUILDINGS

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ABSTRACT

The movement toward a sustainable environment will create a new architecture, and that architecture will draw to itself new methods and new systems of building. The Coupled Pan Space Frame is a new structural system that will support this movement towards an integrative architecture.

1. INTRODUCTION

As the development of the Passive Solar movement proceeds from components to systems to buildings, it becomes more important to develop and identify building components and systems which are particularly supportive of building energy conservation. The Coupled Pan Space Frame (CPSF) is a structural system uniquely suited to be a structural/mechanical framework for solar conserving buildings. The CPSF is a post tensioned concrete space frame that is light in weight (100 psf) capable of long two way spans (60' x 60' or 70' x 30') with high load carrying capacity (130 psf). Of particular interest is the fact that the CPSF has systems of voids running through it parallel, perpendicular and at diagonals to the directions of the space frame grid members. This "system space" is sufficient to accommodate all mechanical and electrical requirements of large, complex buildings. In addition excess system space not specifically occupied by other systems may be used as an air plenum.

In solar conserving buildings a structural configuration of this substance and configuration holds unique promise. In large buildings the mass of structural material is enormous. If this mass could be made accessible for heat or coolth storage, a substantial portion of the building energy load could be integrated within the structure itself. The Coupled Pan Space Frame makes this a reasonable proposition. The large surface-area-to-volume ratio of the CPSF provides for excellent heat exchange characteristics, while the air plenum within the depth of the space frame provides the space to move heat/coolth in and out of storage.

The CPSF is highly integrative, combining structural, mechanical, heat mass and heat transport in one cost effective system. It could become a major tool in integrating energy issues with building and architectural concerns.

2. INTEGRATION

The history of Modern Architecture is a history of increasing differentiation and specialization. As materials and systems became more complex, both the design and the construction of buildings were subdivided into evermore isolated systems designed and built by evermore specialized professionals and tradespeople. Separate curtain walls and structural systems replaced bearing walls. As mechanical systems became more complex and more sophisticated, building designs became unresponsive to climate and permitted a detached aesthetic purity to develop and prevail. It was a self perpetuating trend. Large buildings were airconditioned year round due to the multiplied load caused by the added mechanical and electrical systems themselves. Mechanical systems consumed 60% to 70% of the building budgets and in a number of hospitals alternate "floors" exclusively housed greater volumes of mechanical space (called "interstitial space") than the actual useable space of the building.

In most large buildings structure was separated from the various systems and these systems were hidden from view by "false" ceilings. (Once called the Soft underbelly of America.)

The appearance of buildings had little to do with their substance or their structure. At the height of the Modern movement, what one could see from the curtain walls on the outside to the moveable partitions and hung ceilings inside became more and more simple, belying the more and more complex technology that was necessary to make these buildings of such poor human and climatic accommodation function at all.

The emerging movement for a sustainable future with its concerns for conservation and solar energy is creating conditions for a new architecture of substance and response. The first steps have been relatively easy. Because large buildings have performed so poorly, it has become fairly common during the past few years to see relatively conventional buildings emerge which consume only a fraction of the energy of their predecessors. In the future when architecture gets to the heart of the problem and truly sustainable buildings and cities are built, a new architecture will have to emerge. It will be integrative as opposed to the dis-integrative, additive architecture of the immediate past.

While many conceptual and analytical tools for solar conservation are already available, still, materials and construction systems which are available were designed to fit the additive approach to building. It thus becomes of great importance to those developing the new architecture to seek out and develop systems that are supportive of an integrative approach to design. The Coupled Pan Space Frame is such a system.

3. THE COUPLED PAN SPACE FRAME

Space frames have been of interest in architecture for some time. Most all of them have been made of steel or aluminum, as for example in the excellent structures of R. Buckminster Fuller. The great American architect Louis I. Kahn tried to develop space frame like structures in concrete for several of his projects including the Yale Art Gallery and the Richards Medical Laboratories at the University of Pennsylvania, but because of cost and construction problems, none of the structures in his realized designs were either cost effective enough or useful enough to have been used by others. This indeed has been the fate of all attempts to date by architects to produce a concrete space frame for the building industry.

The Coupled Pan Space Frame is unique in that while in being a space frame, it is a structure with many desirable characteristics: it is in a way, a negative design. Instead of being a design for a desired type of structure (that is, a concrete space frame), it was at first an idea for a simple way in which to build a space frame.

The coupled pan forming principle is the key to using simple means to make a complex structure (see Fig. 1). In poured concrete construction, in effect two structures must be built. First a set of formwork on temporary supports (shoring) is constructed out of wood or some reuseable material (steel, fiberglass). Then reinforcing steel is set, concrete is placed in the forms and after curing the shores and forms are removed revealing the completed concrete structure. The final structure then is the negative of the forms which were used to cast it. If one pays particular attention to the process of construction, a complex set of reuseable forms may be developed into a simple process for making a complex structure. This is the process of the CPSF.

To cast the CPSF an array of fiberglass forms, similar to waffle slab forms which have been in use for many years, is set in a grid. In fact the forms appear identical to waffle slab forms except that the four corners of the pan have been removed on a 45 degree angle creating an octagon from what had been a square at the top of the forms. Above these bottom pans, an inverted grid of essentially similar top pans is interlocked with the bottom pans. The top pans are offset half a grid in both directions from the bottom pans so that the center of the top pans occurs above the intersection of four bottom pans. Top pans are then coupled to bottom pans (reinforcing and posttensioning steel having already been set) and concrete is placed in the voids created between the coupled pans. After the concrete has cured, forms are uncoupled, the bottom forms are removed from below as in standard waffle slab construction and the top forms are removed from above, revealing the completed space frame. The network of horizontal voids (system space) running through the CPSF is a result of the offset between top and bottom forms.

An extensive research program centering on the CPSF has been carried out under a grant from DHEW ("Development of an Integrated Building System for Hospitals" US PHS-MS001-02). The research program built, analyzed and tested a number of full-size CPSF structures up to 60' x 60' in size. The results of that research were published in a book which also presents a design method that may be used to organize the system requirements of buildings with as complex mechanical needs as hospitals within the system space of the CPSF(1). A cost analysis that shows the CPSF to be an economical, cost effective structural system is presented as well.

Many structural, mechanical and architectural studies determined the final form and dimensions of the CPSF (Figure 2). The basic dimensional and structural characteristics are these:

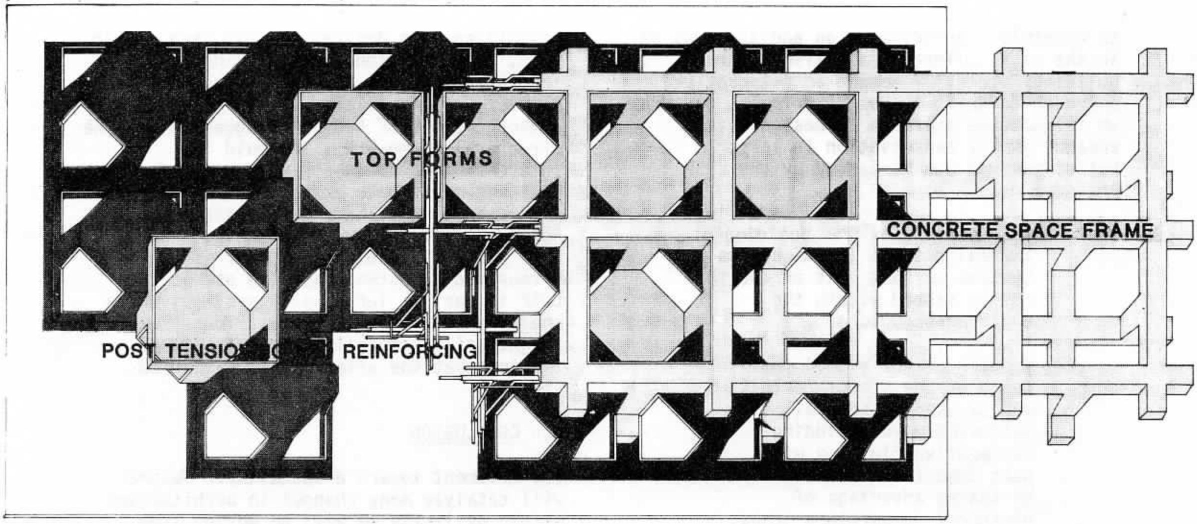


Fig. 1 The Coupled Pan Space Frame Construction System

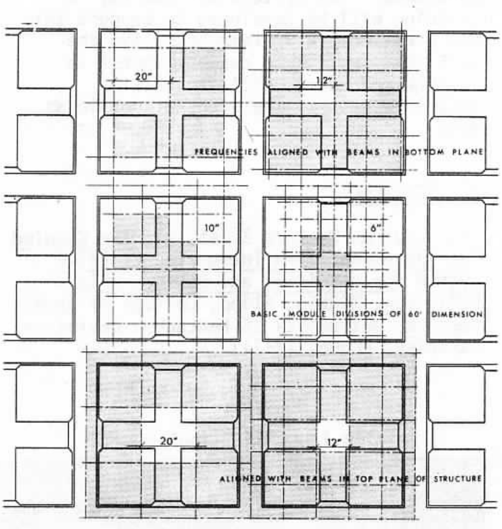
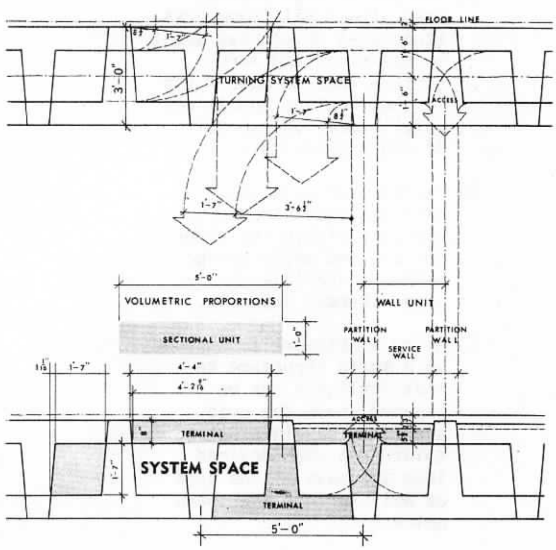


Fig. 2 Dimensions of the Space Frame



SECTIONAL RELATIONSHIPS DETERMINED BY THE COUPLED PAN SPACE FRAME

Coupled Pan Space Frame
Spans: 60' x 60' or 30' x 70'
Dead Load: 100psf
Live Load: 130 psf
Depth: 3'2" (3'0" without recessed top slab)
Module: 5'0" center to center
System Space: 19" x 19" (2 per module in two directions)
19" x 26" (2 per module in two directions)

4. SOLAR INTEGRATION

The CPSF is the framework for the entire floor-ceiling system. It makes a place for all other building components: from the systems that run within it, to the floor that it supports above to the lighting that it supports below, to walls and services that emerge from it to spaces both above and below. In contrast to current ways of building which are an addition of specialized systems, the CPSF with its systems integrated within becomes a fabric out of which a building organically grows. While it seemed to be a reasonable approach to assemble a building in an additive way as in the past, climate responsive solar buildings virtually demand an integrative approach to design. Some attributes of such an integrative approach to design which enhance energy conservation in larger buildings, and can be served by the CPSF include:

1) The coupling of the building's thermal mass to its mechanical systems so that heat or coolth may be stored within the building structure.

2) An open plenum within the depth of the structure that may be used in several different ways including the passive flushing of heat from the structure by taking advantage of nocturnal temperature drops.

3) The use of high thermal mass structural frameworks (concrete) which have small member sizes and large surface area to mass ratio so that heat or coolth can quickly move in and out of the storage mass.

4) Having available space as well as added structural capacity within the plenum for placing phase change storage materials for added thermal capacity.

5) Using a gridwork as opposed to a solid structure so that skylights can be located above the grid providing daylighting and solar gain when desired into the mass of the grid as well as into the space below.

Very early in the movement, the solar passivists were critical of active projects because they were typified by solar hardware bolted on to unrelated, unresponsive buildings. We have taken several steps beyond where we were then, but unfortunately most larger solar projects are still an addition of various conservation measures with solar devices and systems to an otherwise conventional additive building, rather than a total integrated design. One of the most integrative of recent solar buildings, the Hooker Chemical building in Niagara Falls, N.Y. (for which this author was an energy consultant) takes a big step in making the entire skin of the building energy and climate responsive, giving it the potential for controlling and maximizing when desired, daylighting, solar gain, thermal chimney ventilation, and insulation. Other aspects of the building, however, remain relatively conventional, although the CPSF had been suggested for the structural framework. It would be interesting to speculate what sort of building might have emerged and how its performance might have been altered due to the characteristics listed above, had the CPSF been utilized. The reader is encouraged to extrapolate the use of the CPSF in various large solar projects where one or more of the listed attributes were sought using conventional means, and imagine what the effect might have been.

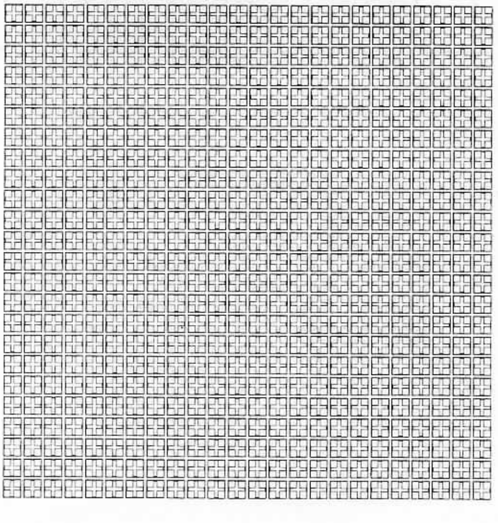
5. CONCLUSION

The movement toward a sustainable future will catalyze many changes in architecture. Little by little we will be moving from surface and style to structure and substance. New systems and new ways of building will be developed to support this new architecture. Frameworks like the CPSF that facilitate responsiveness to climate and energy will facilitate responsiveness to the needs of people as well.

6. REFERENCE

(1) Levine, Richard S. et. al, The Coupled Pan Space Frame: An Integrated Building System for Hospitals and Other Complex Buildings, XPRESS, 414pp, College of Architecture, University of Kentucky, Lexington, Kentucky 40506, (1971).

Table 1. CPSF Planning Grid



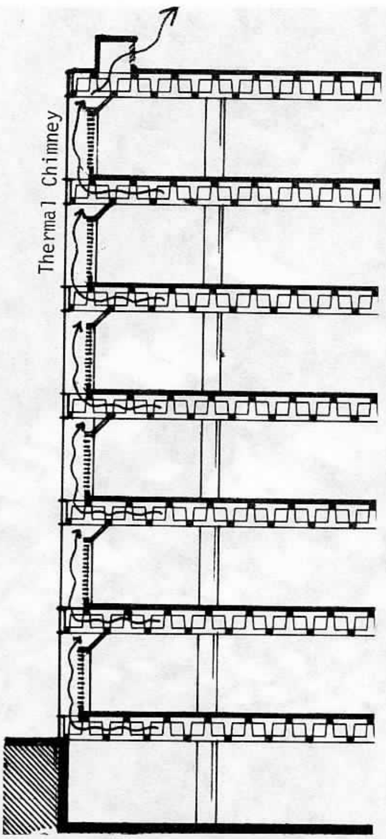


Fig. 3 "Hooker" Type Building Using CPSF as Structural Framework

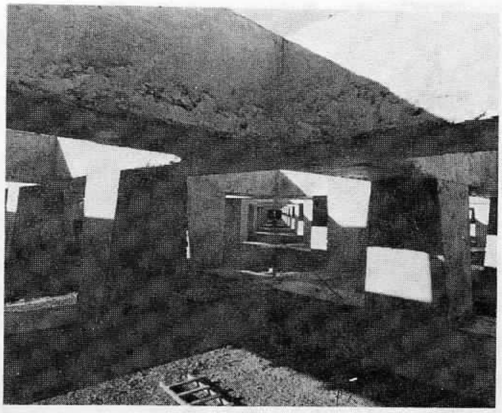


Fig. 5 Looking Through the System Space (Diagonal)

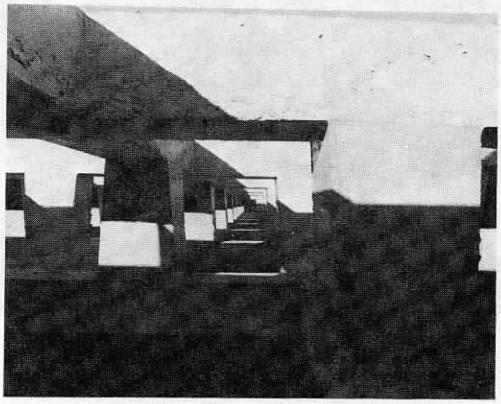


Fig. 6 Looking Through the System Space

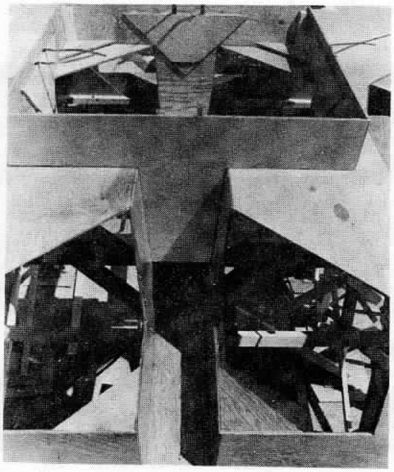


Fig. 4 CPSF Bottom Forms and Vertical Reinforcement

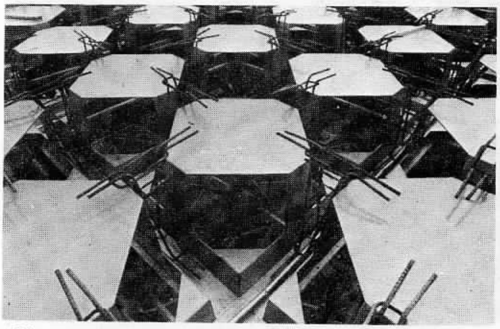


Fig. 7 Shoring, Formwork, Reinforcing and Posttensioning

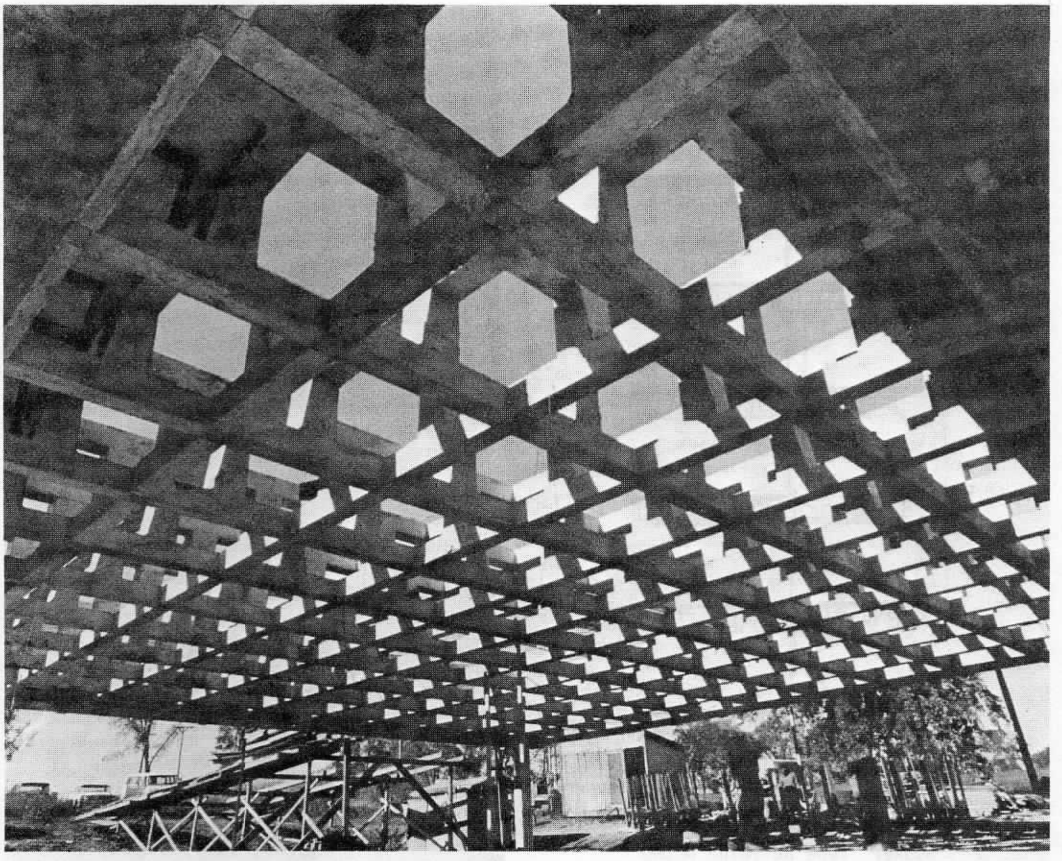
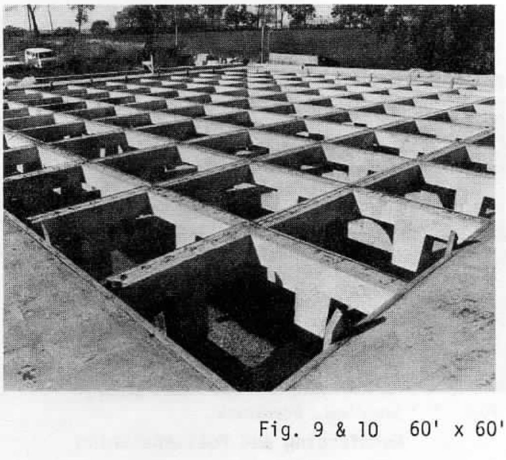


Fig. 8 60' x 60' Test Structure



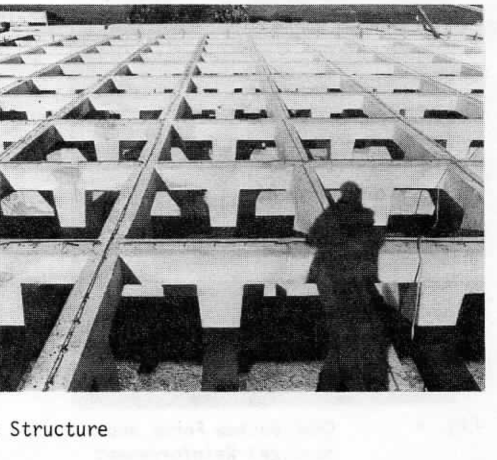


Fig. 9 & 10 60' x 60' Test Structure