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## Building Technology: Potentials and Problems

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In discussions of the large volume of building—particularly housing—projected for the balance of this century, it is often said that we have the necessary technology and that no great improvements are either necessary or likely, but that other factors stand in the way of its full application. It is also said that costs of building, especially housing for low- to moderate-income families, are too high but that technology cannot substantially reduce them, and that they must be brought down in other ways, mainly by financial means such as interest subsidy, preferential tax treatments, and so on.

There seems to be a contradiction here. If costs are too high and technology can not substantially reduce them, then technology is inadequate. It may be true that no great improvements are possible; it may also be true that we need only to utilize fully our existing technology. Perhaps we are in the position of the dirt farmer who refused to send his son to agricultural school because, “we don’t farm as good as we know how right now.”

To determine whether we can make full use of existing and potential technology we must (1) see what those technologies are; (2) examine the complex interactions of technology with social, political, and economic constraints; and (3) determine what must be done to remove those constraints. This is obviously an enormously complicated subject, only a few facets of which can be touched upon here.

### Elements of Industrialization Existing Technologies

As this audience well knows, there is no single technology; there are many, and none universally applicable to all building situations. We have many traditional methods of construction developed during centuries of trial, and based upon diverse materials, structural principles, and methods of environmental control. When well organized and efficiently carried out, these often still offer the best solutions to given problems. Nevertheless, we are acutely aware that they have their shortcomings in the face of today’s situation and tomorrow’s demands. The search for improved technologies moves forward on a worldwide scale. We hear much about industrialization, building systems (also called systems building and the systems approach), the performance concept, organization and project control, and how these promise to help solve our problems. We may examine them briefly to see where they stand today, and where they appear to be going.

### Industrialization

“Industrialization,” as is true of many commonly used words, means different things to different people. To some, it is merely a subterfuge to avoid the bad odor of “prefabrication.” To others, it is the panacea for all building ills. As used here it means not only shop

fabrication, but also the efficient organization of construction that combines shop fabrication with orderly site assembly.

There is no dearth of industrialization schemes. The Patent Office is full of them. In many respects they are more advanced (that is, more widely employed) abroad than in the United States. Some are based almost entirely on traditional technologies adapted to shop fabrication, some employ moderately advanced ideas, some are exotic. They can be classified in various ways. One such classification is into boxes, big panels, and pieces.

### Big Boxes

Boxes are room-sized or larger enclosures that may constitute the entire building, as in trailers and mobile homes, or they may be assembled into larger buildings such as apartments and hotels. They may comprise only the structural shell—indeed, some walls may be fitted in only after the major portion of the building has been completed—or they may be completely prefurnished with all utilities, carpets on the floor, and pictures on the walls. In one publicity stunt, a “tenant” and his family rode their hotel room from the ground to its place in the building.

Big boxes may be heavy or light. Some concrete boxes weigh 80 to 100 tons. Others, such as those built by the mobile home industry, are extremely light and can be towed long distances on wheels. In at least one instance, wood-frame boxes were hauled 600 miles to their final destination, where they were stacked by a light mobile crane to provide dwelling units. Some boxes unfold from a compact arrangement, conforming to highway restrictions, into full-sized units. There are many variations. Most strive for the fullest possible prefurnishing and the incorporation of all utilities. This is the attractive feature of the big-box approach, and one of the reasons for the spectacular growth of mobile homes.

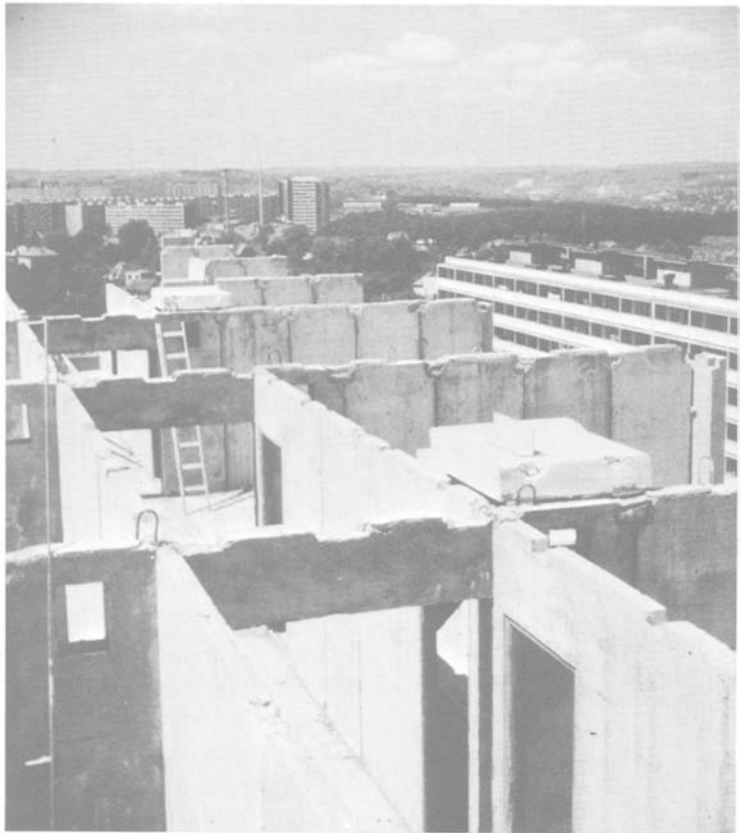
### Big Panels

Big panels are wall-sized slabs and large floor units that are assembled at the site into the finished configuration (Figures 1, 2). A single panel may form part of several rooms. Panels may or may not be finished on both sides: it is common for both surfaces of concrete panels to be so finished, whereas wood-based or other framed panels may have only one finished side to allow for easy joining and the field incorporation of utilities. As in the case of boxes, big panels may be heavy or light, depending upon materials and method of fabrication.

The obvious advantage of big panels over boxes is that boxes are bulky, while panels can be efficiently stacked for transportation. Panels, on the other hand, call for many more joints to be made in the field and seldom permit the degree of prefinishing and shop incorporation of utilities and equipment possible with boxes. Many of



**Figure 1**  
Industrialized concrete building panels.  
Thamesmead.



**Figure 2**  
Concrete-panel construction. Prague.

the advanced European systems are based on big panels, usually concrete.

## Pieces

The term "pieces" refers to smaller units than big panels, usually columns, beams, and floor slabs, assembled at the site to provide the structure into which are inserted nonstructural panels or field-fabricated parts such as partitions. The line between industrialization and traditional construction can easily become blurred. The objective may be greater flexibility of arrangement with a smaller number of different units than might be possible with big panels, or it may be simpler fabrication equipment in the shop, or simpler and lighter erection equipment, or pieces small enough to be handled by manpower alone. More joints are usually required than with boxes and large panels, but the joints may be simplified by being put at points of low stress. The amount of field finishing and field incorporation of utilities is generally greater than with boxes and big panels, but this can be reduced by careful and ingenious design.

These approaches are not mutually exclusive, nor do they preclude mixtures of industrialized and traditional methods. The latter is the rule; few, if any, of the new technologies make no use of traditional procedures. Box construction is likely to employ some panels and pieces; the dividing line between big panels and pieces is not sharp; foundations are almost certain to be field fabricated; and it is often more economical to cast floors in place than to use precast slabs, especially when plans are irregular and nonrepetitive.

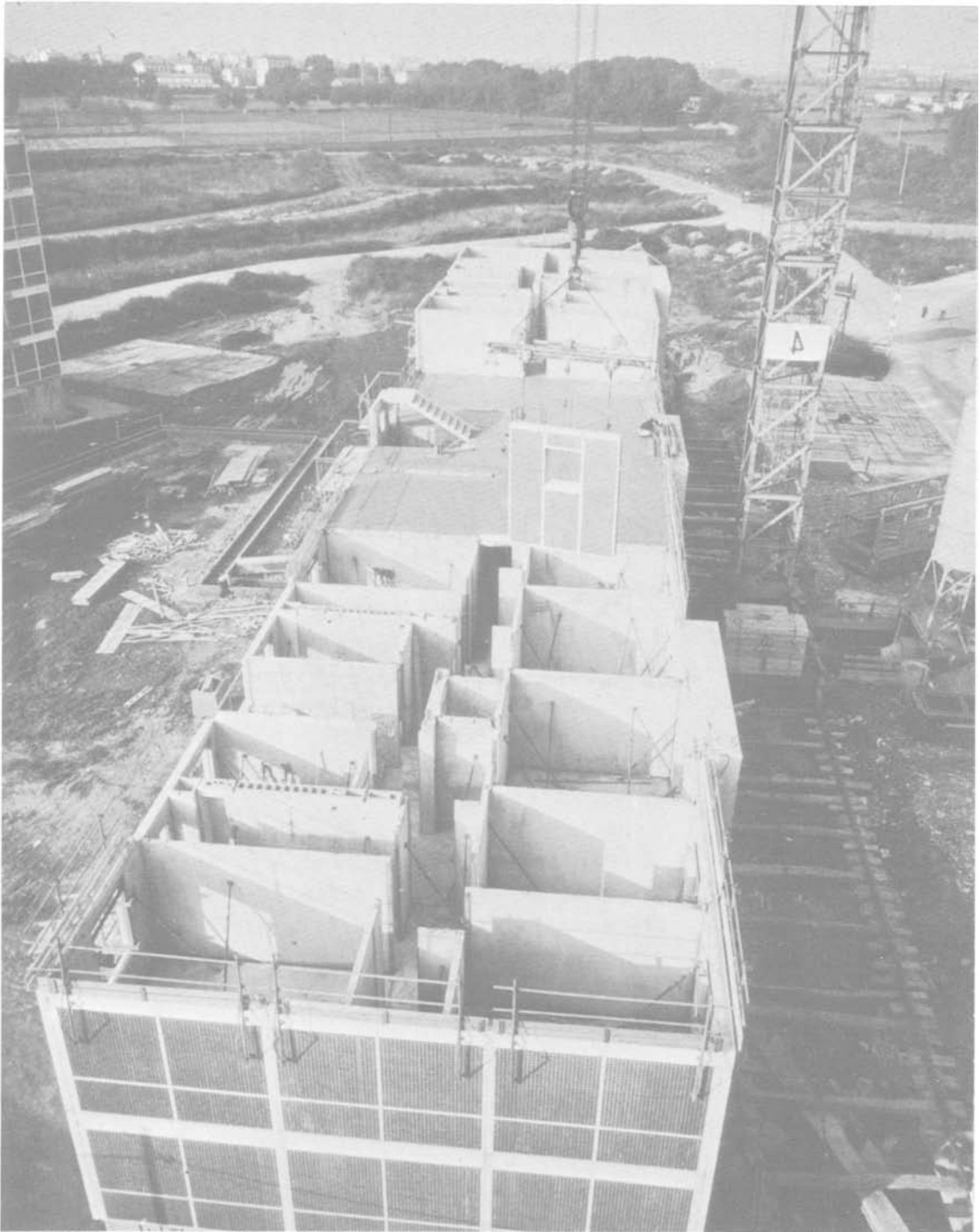
## European Practice

In Europe, industrialized housing is much more widely practiced than in the United States. There are many reasons. The devastation of war created an enormous demand at the very time that the depletion of skilled manpower left traditional handicraft methods incapable of coping with it. Government involvement in housing is much more extensive than here and provides a large single market that makes industrialization both possible and attractive.

Most of the European systems are based upon big panels (Figure 3), although some use has been made of boxes in various countries, including the USSR, and boxes may find increasing favor in the future. Big panels are predominantly concrete, although, as will be seen, there are some notable examples of other materials and of composites. Big panels have spread throughout Europe from methods originating in various countries. The notable innovations originating in Scandinavia and France in Western Europe parallel extensive large-scale development in Eastern Europe.

## Materials

Advances in materials technology range from modest to exotic. Some are already in use, others appear to be promising for the near future, still others are in the distant future or may not find their way into buildings at all. Only a few can be mentioned here.



**Figure 3**  
Simultaneous erection of precast wall  
panels and site casting of floors. Milan.

Expansive cements and controlled-set cements are recent additions that promise to overcome some of the problems with concrete—notably, shrinkage and cracking upon curing—and that may provide the ability to control the cure time of concrete to meet varying conditions. If questions respecting long-time stability, creep, and related aspects of expansive cements are answered to the satisfaction of building users, and if the set of concrete can be closely controlled under site conditions and in the shop, these materials can provide valuable additions to the existing array of cements and their modifiers. Self-prestressing may be possible; if so, it will obviate the necessity for much of the equipment now associated with prestressing or posttensioning. The usefulness of concrete, already great, may be enhanced even more.

Steels stronger than the old reliable structural steel so long used in building have already found uses, as have high-stress bolts and the consequent virtual disappearance of hideously noisy rivets. More steels can be expected, leading to still more flexibility in design. Sprayed-on fireproofing has created a minor revolution and has helped steel to regain some previously lost applications. Steels that form tenacious rust surfaces have appeared. New design concepts, such as the staggered truss and greater use of cable-supported structures, can help to provide economy and flexibility.

Enhanced dimensional stability, increased hardness, and integral finish are being supplied to wood by deep impregnation with plastic monomers subsequently polymerized in situ by chemical means or by penetrating high-energy radiation.

Plastics continue to provide one of the fastest-growing sources of material for floor and wall coverings, durable finishes, high-performance engineering adhesives, tough transparent enclosures, piping, hardware, film, insulation, and many other uses. The number of these applications will undoubtedly expand; new uses will be found as designers become more familiar with the various plastics and questions respecting their performance are resolved.

Sealants, although a small item, have already become critical in building, and increasing industrialization, with its need for field joints, will step up the demand. Problems still remain; chiefly, quality control of workmanship in the field.

Photochromic glass is expected to help solve the old problem of sun control. By darkening as light intensity increases, and vice versa, such glass can assist in maintaining fairly uniform levels of light and in overcoming glare. Chemical tempering should help to remove the present limitations of tempered glass.

High-strength mortars and adhesives that provide joints at least as

strong as the masonry units themselves have already resulted in thin masonry walls, brought about changes in techniques, increased production, and made precast masonry panels possible.

Among the possibilities being explored in laboratories are the combining of inorganic materials, such as concrete, with organic materials, such as polymers, in an attempt to marry the hardness, compressive strength, and durability of the former to the toughness and resilience of the latter, and thereby to gain most of the advantages and overcome most of the limitations of both. Thin toppings for floors and strong stuccos have already resulted from such combinations.

## Composite Materials

Composite materials are among the most promising of all developments. The increasingly severe demands imposed on materials by our building practice often cannot be met by simple single-component materials; they call for the combined behavior of several materials acting in concert to provide properties not attainable by the constituents acting alone. An example may serve to illustrate.

The Greater London Council recently decided to construct a number of high-rise apartments in which industrialized components should be employed to the greatest practicable extent. Utilizing its power to set its own building standards, it decided upon a series of performance requirements for the exterior walls. These should be factory-produced panels able to withstand 80-mile-per-hour winds, having a U-factor not greater than 0.20, an average acoustical attenuation of 35 decibels, zero flame-spread on the surface, one-hour fire penetration resistance, minimum weight, minimum thickness, and should require only minimum maintenance.

After several years of development, a composite wall panel emerged that had an outside shell of mineral-loaded molded glass-fiber-reinforced plastic with a durable, renewable, baked-on polyurethane finish; a 3- to 4-inch thick filling of wire-reinforced foamed concrete weighing only 20 pounds per cubic foot and attached to the shell by a flexible bond layer, and an inner facing of reinforced gypsum plaster bonded to the core with a layer of bitumen that simultaneously provided a vapor barrier. This panel easily met all requirements, weighed less than 20 percent as much as traditional masonry or precast stone concrete, and was one-third the thickness. Foundations and steel frame were lighter than for traditional construction. The builders could assemble panels to the supporting steel and place them so rapidly, with an ordinary tower crane, that the manufacturer could not keep pace with them. In-place cost was competitive with standard construction, even though the first shells were made in the United States and shipped to London for completion.

This is only one example of the growing use of composites in build-

ing. Many more can be expected. The building industry may borrow from developments in space-vehicle design, such as filament-wound structures and high-performance fibers, filaments, and whiskers.

Filament winding makes maximum use of high-strength filaments, mainly glass, by winding continuous filaments impregnated with a matrix, such as synthetic resin, upon a simple mandrel of the desired shape, the orientation of filaments being controlled to meet the expected stresses. Extremely high strength-to-weight ratios are achieved, and the only limitation on size is the size of the relatively simple equipment required. Some limitations on shapes attainable and on openings for windows and doors exist, but the technique is feasible. The idea of winding on a form deserves further attention.

### High-Strength Fibers

The attainment of high strength by drawing materials into fine filaments is not confined to glass, the strength of which rises from about 5,000 psi for massive glass to better than 500,000 psi for commercial filaments, and still higher in the laboratory. Materials capable of being formed into filaments commonly exhibit comparable strength increases. It is for this reason that space-vehicle research is concentrating on such materials as boron, beryllium, silicon carbide, carbon, and graphite. These are not only light and extremely strong, they are in many cases much stiffer than glass fiber and steel. This is an important factor because stiffness, rather than strength, is often the determining factor in design. The glass-fiber-reinforced plastic "House of the Future," for example, was designed for stiffness; strength was more than adequate.

Still more exciting from the technical viewpoint are the "whiskers," extremely fine single-crystal fibers of materials such as aluminum oxide (sapphire), whose strength and stiffness, measured in millions of pounds per square inch, approach the theoretical maximum attainable values.

Costs of most of these materials, ranging as high as several thousand dollars per pound, are at present completely prohibitive for building, and may continue to be; but projected costs of carbon and graphite and some of the carbides are not unreasonable, and these latter materials may soon become economically competitive elements of high-performance composites for building.

### Composite Structures

We are not fully exploiting those composites that we have, such as glass-fiber-reinforced plastics, nor are we fully utilizing the possibilities of composite structures. For example, in a study carried on by two graduate students, it was demonstrated that in a 150-foot ribbed lamella vaulted roof, concrete ribs could be combined with diamond-shaped, double-curved, eight- by eighteen-foot reinforced-plastic infilling panels, one-tenth inch thick, capable of carrying the



imposed wind and snow loads, and transmitting daylight into the interior, at a saving of one ton of weight per panel. The concrete ribs would provide the primary structure, and the panels would first act as forms and then as lightweight, light-transmitting secondary structures; concrete and plastic each making its best contribution to the whole.

The future for composite materials and composite structures—in which several functions are combined to attain superior performance—seems bright, but there are real problems that must be solved, as will be brought out later.

## **Systems**

### **Systems Analysis**

Much is heard today about systems, systems analysis, and the systems approach. The building fraternity is accused by systems-oriented space practitioners of not employing the systems approach. The building designers retort that they have always designed whole systems, that this is the essence of building design, and that buildings are complex systems involving the interaction of human and technical factors, whereas space systems are largely technological devices, complicated in detail, but simple in essence, upon which human whim and prejudice have little influence. The form and functioning of a jet plane or a lunar vehicle are determined almost entirely by technological requirements; the form and functioning of a building are dominated by human attitudes and requirements.

There is much truth in both viewpoints. The superb functioning of the lunar probes is the result of an extremely sophisticated, total systems approach in which the interrelationships of all the parts, including the human occupants of the capsule, are carefully studied and correlated in detail and in combination, and sophisticated mathematical procedures, employing the most advanced computer technology, are employed to optimize the resulting intricately related requirements. It is recognized that the human brain, superb computer that it is in many ways, is incapable of solving or keeping track of more than just a few simultaneously reacting factors at a time, and that mathematical tools must be relied upon to handle multifaceted problems.

To a limited extent, those systems tools are being utilized in building design. Structures are commonly analyzed and designed by computer; so are many mechanical subsystems. Traffic studies use mathematical models. There are other instances in which a start is being made. These usually have to do with portions of the whole problem.

The crucial part of the design of buildings and building complexes is the conceptual stage in which the many requirements of the owner (often badly formulated, only vaguely understood, and subject to change), economic factors, political and legal constraints, social influences, the site, and technological limitations of materials and

equipment must somehow be put together into a coherent optimum design. This has not to any noticeable extent made use of the tools of formal systems analysis.

Perhaps the problem of building design, with all its complexities and human uncertainties, is not amenable to solution by systems analysis and synthesis. What seems to be true at the moment is that a combination of formal systems analysis and the empirical intuitive approach of the master designer must somehow be combined to the benefit of each. Having struggled through the mass of requirements and found a workable solution, it is difficult for the designer to divorce himself from it in his search for other possible solutions; furthermore, he may not have time. A considerably better approach is for him to set down the important relationships among the various aspects of his design problem in such a way that they can be handled by a computer, which can then provide many alternative solutions. Space allocation is one distinct possibility. The crucial point is that the computer, certainly as matters stand now, will not distinguish between acceptable and unacceptable solutions. This must be done by the human designer; his judgment and sense of fitness must lead to the decision. What the computer can do is provide him with more choices.

Parenthetically, there seems to be a curious contradiction in the attitudes of many architects toward the computer. It is dismissed as a mere mechanical tool, utterly incapable of doing the creative work of design and therefore of no consequence; at the same time, it is feared as a monster that will take over. The truth lies somewhere between, and it seems more likely that the computer, properly employed, holds the promise of relieving the architect of drudgery, freeing him for the creative tasks that are beyond the computer's capacity. But this will not happen until the profession makes a determined effort to understand and use the computer.

## Complex Systems

One of the dangers in the manipulation of large complex systems is that decisions made and actions taken on the basis of even the best judgment and greatest experience can often be disastrously wrong. This is true because the human mind simply cannot comprehend or visualize the intricate, hidden, but extremely sensitive interactions that occur in such systems. Industrial dynamic analysis has shown that violent fluctuations in industrial processes may easily be brought about by the very steps taken to avoid them. A recently completed study of urban dynamics has shown that steps advocated to provide housing and to rescue the decaying central cities may easily hasten that decay and worsen the housing problem (see Chapter 5). It is entirely likely that the decisions taken to avoid unwanted situations in the design of large complex buildings may lead directly to similar situations. If systems analysis can help to avoid such errors, then designers should make every effort to avail themselves of this new technology.

Even a relatively simple example may illustrate. All too often when a lighting problem arises the obvious answer is to increase the level of illumination. Indeed, this idea has become so firmly fixed that code requirements have constantly been rising. What is actually wanted is better visibility, which may be only marginally related to light level. Contrast, glare, direction, and subtle psychological effects—the quality of the luminous environment—may be much more important than the level of illumination, which, in any event, gains nothing when raised beyond a certain point, and may bring about undesirable secondary effects such as overloading of the cooling system. Only by considering the total system and its interactions can an optimum answer be found.

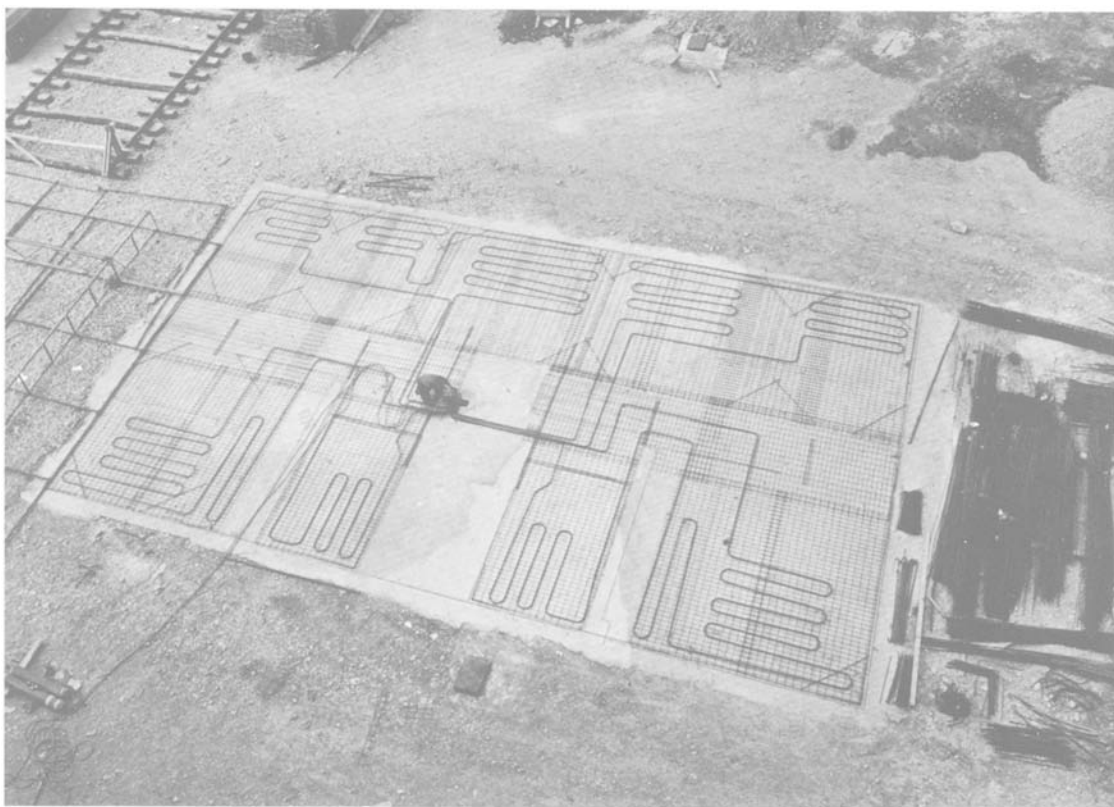
Illumination is only one aspect of the whole subsystem of environmental control. Relatively little study has been made of the combined effects of light, sound, temperature, humidity, and other factors acting simultaneously, as they do, upon human beings. Each factor by itself has had extensive research, but the combination of all of them has had little (Figures 4–6).

## Building Systems

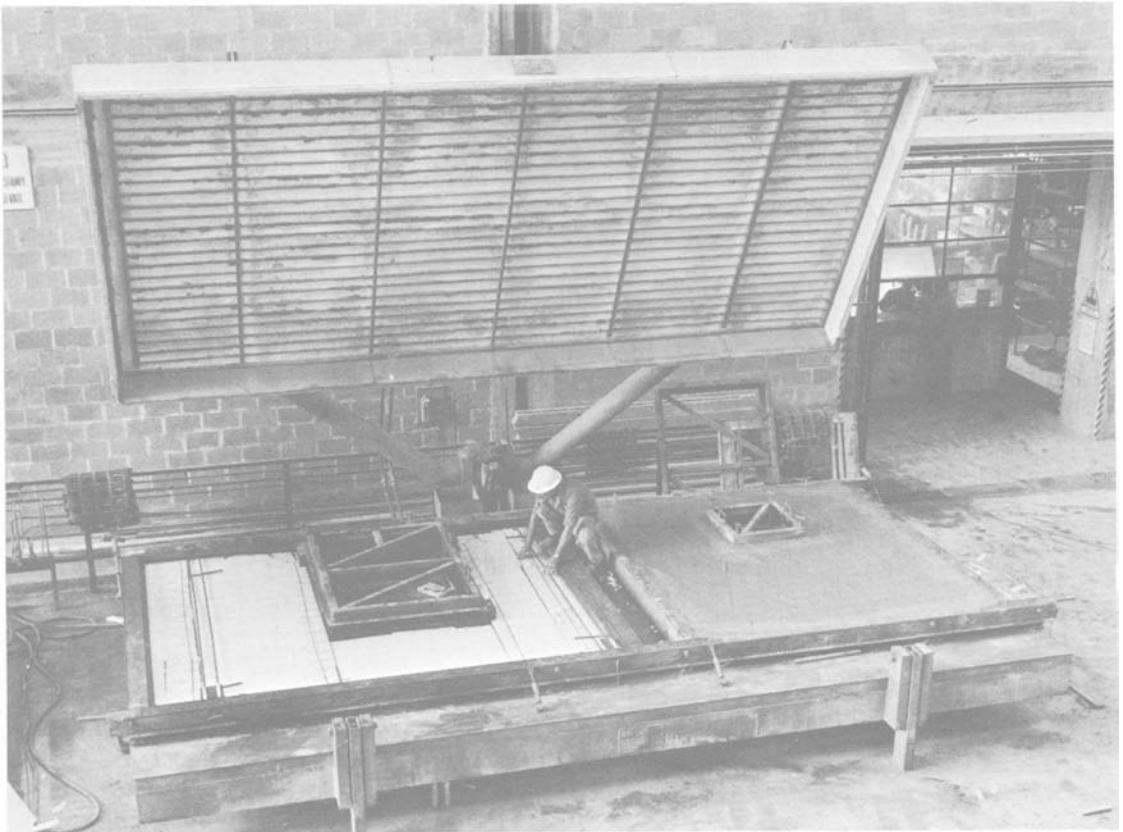
When the many actual and proposed building systems are examined, it becomes evident that the vast majority, both here and abroad, concentrate on structure. As we all know, in today's buildings, structure is an important, but not overwhelmingly important, part of cost. Control of the internal environment—light, sound, temperature, humidity, odor, air movement—is a major factor, and the associated costs are high. Yet, the total systems approach seems all too often to be neglected. The structure and envelope are carried to the point of no return, and then environmental controls are added, sometimes, it seems, as a cosmetic unskillfully and perhaps futilely applied.

The whole system of structure and environmental controls must be considered together; it is their combined action that governs the quality of the environment. Simple changes in structure can often enormously affect the acoustical environment; advance consideration can simplify and increase the efficiency of mechanical systems, and illumination can be made effective or difficult by structure and envelope. The technology of integrated environmental control systems and the technology of coordinating such integrated systems with structure and envelope have not advanced far; much more must be done if efficient cost-reducing overall building systems are to be achieved.

It often happens that if all aspects of a system are not carefully considered together, seemingly insignificant details suddenly become important. I can give a simple example. In a large European industrialized housing project, it was noted that, by careful planning, a large precast floor panel could be lifted from the special truck by an efficient traveling tower crane and put into position on the eighth

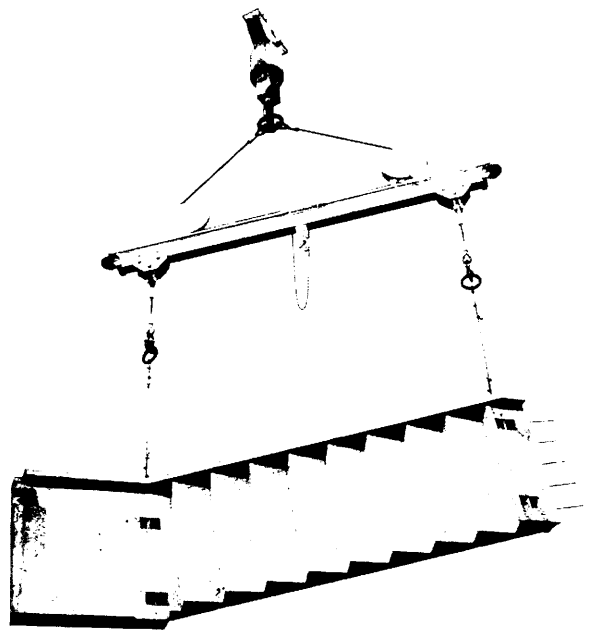


**Figure 4**  
Preassembly of reinforcing steel, radiant-heating coils, and utility lines. Milan.



**Figure 5**  
Heated casting bed for concrete wall panels; foamed plastic insulation in place. Milan.

**Figure 6**  
Precast stairs.



floor in four minutes. To place the necessary additional reinforcing steel in the joint for structural continuity and to fill the joint with grout by hand took at least as long. Later finishing of the joints in the ceiling, and finishing of wall and partition joints with moldings or other devices, all took much additional time. In such schemes, it often turns out that the cost and time involved in handling the joints is a major factor. This is one reason why skepticism is often voiced respecting the superiority of industrialization over traditional field construction. Clearly, a total systems approach must find better answers if industrialization is to fulfill its promise.

A total systems approach must integrate the functions carried on in a building with structure, environmental controls, internal transport, utilities, and efficient construction, operation, and maintenance into an optimum solution. That it must also be visually acceptable goes without saying.

An example of what may happen when more than one aspect is taken into account may illustrate. In connection with a study of component construction in single-family detached dwellings, various modular sizes of wall and partition panels were compared with respect to flexibility of arrangement and cost. The conclusion reached was that many combinations were about equally acceptable and that the module should be based, not on structural requirements but first, upon the most efficient use of dimensions dictated by heating, plumbing, and kitchen equipment, and second, best panel sizes for windows and doors. Plain structural panels could be virtually any modular size that met the first two criteria. If these modular requirements were met, great flexibility in arrangement could result, that is, many efficient unstandardized plans could result from a small number of standard components.

In spite of all attempts to allow for every contingency, innovative technologies may run into unforeseen situations, with far-reaching consequences. When a gas heater exploded and blew out the corner panels halfway up in a panelized industrialized building, allowing collapse of that corner, the results reverberated throughout the industrialized building community. It was realized that although the design conformed to all code requirements, this particular contingency had not been anticipated. New regulations have meant extensive and expensive strengthening of existing panelized buildings and redesign of new ones. In one instance, the ensuing delay in construction resulted in the piling up of components at the fabricating shop and forced a disruptive temporary shutdown.

## **Constraints**

### Public Attitude

So far the discussion has centered mainly upon hard and soft technology; some aspects of physical structure, and some exploratory ideas respecting systems. What about constraints, those factors that may obstruct the further use of better technologies?

There are many, and some, at least, are rooted outside the building industry per se. For example, the intensive study phase of the late In-Cities Program of the Department of Housing and Urban Development brought to light some revealing public attitudes toward new and unfamiliar technologies. Typical reactions were "OK, so long as it's brick," "No Bucky Fuller," "No more concrete prisons," "We don't want skyscrapers," "No crackerboxes," "No ticky-tacky." These attitudes clearly reflect suspicion of, and reluctance to employ unfamiliar technologies, as well as distinct disenchantment with unsuccessful applications, of which there have been more than a few.

Still another aspect of the importance of public attitude is found in the decaying inner city, where inhabitants have forcefully proclaimed that "If we don't build it and control it, we will burn it."

These expressions, extreme though they may be, cannot be dismissed out of hand but must be taken into account as new or different housing technologies are explored.

Rehabilitation poses the greatest need, the greatest challenge, and has so far been the most stubbornly intractable field for new technologies. It entails the most direct contacts with the public. The most starry-eyed and unrealistic promises have been made and broken, and the greatest disappointments and suspicions have resulted. The technology immediately most useful here is probably the application of advanced, sophisticated, efficient organization and control, utilizing mainly traditional building methods, but introducing, as rapidly as possible, new technologies in centralized compact mechanical and electrical systems. Here, new ideas are urgently needed. For example, if new plumbing devices such as dishwashers, laundries, and garbage grinders simply result in overloading already inadequate sewerage systems, little progress will have been made. Ways of reducing water consumption and of more efficiently disposing of wastes are badly needed. This, of course, is not restricted to the ghetto.

#### Industrial Organization

An innovation that does not conform to established industrial patterns may have a difficult time in finding a home. For example, the wall panels for the Greater London Council described earlier were not made of only one material, nor was any one material preponderant. Their use therefore did not coincide with the primary interests of any one manufacturer, and no materials manufacturer took on either their development or fabrication. This was undertaken by a small entrepreneur engineering firm in London, which had to pull together the necessary design, development, and production skills on both sides of the Atlantic to accomplish this modest task. It required an arduous, protracted effort.

This example illustrates a situation that constitutes a serious constraint

on technological progress, when that progress calls for the coordination of materials, equipment, or both, into an efficient system or subsystem. The composite panel of the Greater London Council, not perfect by any means, was able to accomplish by the combined behavior of its materials what no component by itself could do. More advanced and sophisticated systems than the London panels are feasible. They will call for coordinated production involving several industries. But, when a composite component appears that calls for closely coordinated production, we find that industry is not really organized to carry on the necessary research, development, and production.

This is understandable. The principals and research directors of a materials-producing firm find their hands full with their own problems, with which they are at least familiar, without taking on completely new ones. If an innovative idea embodies equipment (such as electrical or mechanical items) as well, the reluctance of manufacturers to participate is even greater.

There are other reasons for reluctance to proceed with systems development that cuts across traditional industry lines. Collaboration on the part of several industries, especially if they are closely related, may expose the participants to action under the antitrust laws. If a composite component comprises several items that are traditionally handled by several crafts, unions may insist that representatives of each craft be involved in the installation, even though they may not actually be needed. Codes may not recognize the virtues of composite behavior and may, therefore, insist that the components be considered separately, thereby negating the objective of the composite.

These impediments notwithstanding, some progress is being made. There is research and development in composite materials and combined systems and subsystems. It is not as rapid or extensive as it should be.

Our system of bidding and awarding contracts can be a strong deterrent to innovation. When the requirement is for three or more suppliers of a given item on an "or equal" basis, and an innovation is produced by only one, that innovation can be effectively blocked. Something else, such as a cost-benefit analysis, should be available to allow single-source innovations to be employed.

#### Design-Production Organization

Innovative technology may not only affect materials and equipment manufacture and the organization of the producing industries, it may significantly affect the organization of the design and building processes. An example may illustrate.

Careful and detailed analyses lead to the conclusion that efficiency,



economy, and speed in the construction of high-rise frame buildings can be achieved by constructing them from the top down: building the penthouses, roof and top floor at ground level, pushing them up, building the next lower floor under it, pushing that up, and so on, until the building is completed. The obvious advantages lie in the elimination of much of the traditional hoisting equipment and the convenience of doing work at ground level, where components can be delivered directly, workmen do not have to travel far, and the job can be readily enclosed to avoid delays due to weather. The push-up equipment, though rugged, is practicable. The technology is feasible; economy stems from efficient working conditions resulting in speed of erection.

Here the principal problem is organization and control. Before any given floor is pushed out of reach, everything that that floor will need for completion must either be built in or must at least be stored on it, except for small items that can be transported on the building's elevators. Extreme care in scheduling the job must be exercised to make sure that nothing is omitted that may later have to be hoisted a long way, thus defeating the whole system. Items calling for a long lead time, such as elevator equipment that must be installed at the very beginning, may have to be ordered long before the design of the building is finished. This, in turn, means that the builder must be brought in early in the sequence, so that commitments can be made as soon as possible. To achieve the benefits of this particular new technology may, therefore, call for a revision of the usual design-bid-build sequence and certainly calls for much more sophisticated organization and control of construction than are ordinarily found.

## Management Technology

The more closely the new and advanced building technologies are examined, the clearer it becomes that they demand sophistication in the technology of management, organization, and project control. It has often been remarked that the successful European industrialized systems are the well-organized and managed ones. There is no technical magic in any of them that gives a distinct lead over the others. Economics and cost reductions are achieved mainly by efficiency and speed, not by some mysterious low-cost material. Speed calls for close coordination from the very inception of the project; great care must be taken to foresee all contingencies so as to forestall expensive and time-consuming changes, orders must be given for items requiring long lead times, and the design-production schedule must be carefully worked out, showing the sequence of steps and interdependencies. Only a well-coordinated and managed team, representing all aspects of design and production, can accomplish this.

Obviously, such careful coordination and control can be and has been applied to traditional construction with most salutary results. It has been claimed that this emphasis on organization, management, and

control is really the only “new” technology needed in building, and that all else is secondary. While this is patently an exaggeration, it does emphasize the importance of complete control. No matter where this kind of managerial ability comes from—traditional architects, the building fraternity, engineers, or elsewhere—the individual with the capacity will fill the position. As one architectural dean remarked, the man with managerial ability, no matter what his background, will be the architect. Hopefully, he will be sensitive to and sympathetic with good design.

## Prediction

Any innovation entails at least some uncertainty respecting its expected performance. It does not have an extensive proved history, therefore, its long-time behavior is unknown, and everyone waits for someone else to try it first.

Here is one of the most difficult and urgent technological problems. For many purposes, there are no short-time tests that will reliably predict long-time behavior. This is particularly true of weathering, where the problem is compounded, first, by insufficient knowledge respecting the actual microclimate surrounding a given building; second, the complex physical and chemical interaction of the constituents of the microclimate upon the behavior of building materials; and, third, the lack of generally available knowledge concerning the actual behavior of buildings under the many diverse conditions to which they are subjected. We tend to build our buildings and forget them.

The same situation is true of many other aspects of building behavior. Although a given building’s maintenance department may have a good idea of what ails it and what has to be done to keep it going, systematic study of such information is generally lacking, and, consequently, it is not easy to devise ways of predicting behavior because the actual conditions are not clearly understood.

This is not to decry the efforts of such organization as the American Society for Testing and Materials (ASTM) and the American National Standards Institute (ANSI). Their test methods and standards provide the basis upon which the building industry largely depends for control of the quality of its materials and components. However, these organizations are the first to recognize that the basic information upon which their tests and standards depend is far from complete, especially in the areas of prediction of long-time behavior from short-time tests. The building fraternity must assist in providing that understanding.

It is a peculiar situation, to say the least, that the very people who depend most upon ASTM and ANSI standards for building components participate very little in preparing them. They are written mostly by materials specialists rather than by the architects and

engineers who specify them and, inevitably, reflect the viewpoints of the materials specialists. This is not the fault of ASTM and ANSI; they have long been vainly trying to enlist the active participation of the designers in drawing up those standards. As advanced technology moves more and more in the direction of industrialization and the total-systems concept, it is even more imperative that the designers and producers of buildings become actively engaged in drawing up the basic standards that govern them. The agencies are there; they need only to be employed.

## Evaluation and Certification of Innovation

In the United States there is no established procedure for evaluating and certifying technological innovations in building materials or components. True, as already stated, the ASTM and the ANSI have many widely employed test methods and specifications, and one prominent laboratory issues labels respecting degrees of fire resistance, but none of these constitutes complete evaluation of a new component.

As matters stand, if a major manufacturer brings out an innovative item and tests it in his own laboratories, the results are suspected of being biased. A developer of a new idea who wants to obtain independent tests must find a commercial laboratory, a university experiment station, or some similar testing agency and have such tests run as may appear to be applicable. In any event, when the tests are finished and the report is in, it is quite likely to be met with considerable skepticism. Bias in the selection, conduct, or interpretation of the tests is likely to be suspected, or the testing agency itself may either be unknown to or deemed incompetent by architects, engineers, building officials, and other interested parties. The result is that the innovator has a hard time getting his idea evaluated and accepted. Progress is often agonizingly slow, and a good idea may die before it can prove itself.

This problem has been recognized in Europe, and many countries have set up a system of evaluation and certification patterned after the original French *agrément* procedure. A board of experienced and knowledgeable people, drawn from government and nongovernment backgrounds, reviews carefully all innovative ideas brought before it, examines the supporting evidence, prescribes what tests, if any, shall be run, examines the results, and, drawing upon the experience of its members, issues a certificate setting forth its findings and judgment respecting the item, how it may be employed and how it may be expected to behave in use. The sponsor of the innovative idea is free to use his certificate in advertizing and when approaching architects, engineers, building officials, builders, financial people, owners, and any others. By and large, the *agrément* boards have established themselves so well that their certificates are accepted by the building fraternity and by officials as impartial expert evaluations. In France, where buildings must be guaranteed by designers and builders for

ten years instead of one, insurance companies frequently demand an agrément certificate for any new components and will not insure unless it is forthcoming.

The agrément system as practiced in Europe may or may not be directly transplantable to the United States, but some such central, generally accepted agency could be extremely beneficial in breaking down the existing barriers to the adoption of innovative technologies.

## Performance Codes and Specifications

In an era of rapid technological development, codes and specifications based upon detailed descriptions of how to build can seriously hamper progress, whereas a carefully reasoned statement of objectives or performance can be a stimulus to innovation. Much is heard about performance, and rightly so, but the accompanying problems must be recognized.

First comes the question of what performance is wanted. Clear, hard, and deep thinking is needed to make certain that the performance called for will result in a building that will actually behave as wanted.

It is not enough merely to specify performance, it must also be possible to evaluate it, to see if a component actually behaves as it should. This calls for a clear understanding of what is to be evaluated and may demand extremely sophisticated evaluative techniques. In many instances, these have not been developed.

When applied to building codes, officials must be much more sophisticated and knowledgeable about the performance to be expected. It is much harder to determine whether a given design will meet a two-hour fire requirement than to see if it calls for eight inches of brick.

Designers must assume much greater responsibility for their designs, along with the freedom that design based on performance may allow them. They cannot hide behind a code that tells them they must build thus and so.

These responsibilities and problems notwithstanding, the objective of basing design upon performance is inherently sound and can provide much of the impetus toward technological innovation.

## Labor

This discussion would be incomplete without some reference to labor, but this is an area in which such strident claims and counterclaims, accusations, and assertions with no discernible solid foundations are made, and the field is so full of conflicting statistics, that one hesitates even to touch upon it. Builders vociferously point to the shortage of skilled labor, and labor equally vociferously points out that the unemployment rate in the building trades is twice that in manufacturing, and both are right, because of fluctuations in building activity.

It is undoubtedly true that labor wage rates in building have risen much faster than costs of materials and equipment, but labor insists that annual average take-home pay is not out of line. The craft-union type of organization does not fit the trends toward industrialization, offsite fabrication, and components combining several materials and functions, but organized labor claims that it can and will accommodate to this trend. The ultimate power of the locals to determine local working conditions does not accord with building technologies that depend upon broad regional or national application. Labor says it can conform.

Traditional skills and the long apprenticeships associated with them may not be applicable. One large-scale European industrialized housing producer prefers to start with unskilled labor; he can train operatives in the simple manipulations needed in short order, and they need not unlearn anything. Building agencies in Eastern Europe say that erection requires not more than 25 percent skilled labor, the rest can be unskilled. Clearly, the training programs for new technologies need to be examined. Shortages of the right kind of manpower may yet be the most serious constraint and at the same time the most powerful impetus toward new technologies.

#### Government Policies

Government policy strongly affects building and building technology both directly and indirectly. Most advanced technologies require fairly heavy investment in plant, whether fixed or movable. This, in turn, requires at least a reasonably even production schedule, but building is subject to fluctuations caused not only by weather but by economic and political factors beyond its control. Industry is going to be wary of investing in plant that may stand idle. To appreciate the basis for such caution, one need only recall the disastrous drop in housing starts caused by the 1966 and 1969 credit squeezes.

The announced federal government goal of an additional 600,000 dwelling units per year for ten years, to be superimposed upon existing housing starts, can be either a vastly unsettling or a stabilizing influence upon the building industry. It can, therefore, either stimulate or stifle innovative technology. If the government program is carefully planned and phased into overall building, it can help to fill in the gaps, smooth out the fluctuations, and lend stability; if it is not, it can accentuate the existing swings and defeat its own purpose. Here is a staggering problem in dynamic analysis.

Considerable sums will be needed for research and development to bring existing and potential technology to bear on the production of 600,000 units per year, a figure which will be closer to 800,000 or 1,000,000 per year when the inevitable delays and lead times needed to gear up production are considered. While private industry can and will absorb much of this cost if there is an assured, steady market, as indicated above, some of the developmental costs will

have to be borne by government, just as it has assumed those costs in other fields such as space exploration and national defense.

## Research

To help find answers to the unsolved problems of technology and its constraints will require research. The building field is notorious for its uneven, relatively low level of research. Research is extensive in materials and equipment but spotty or nonexistent in areas that have to do with the total building, its functional and physical behavior, design as a total system, and other aspects not directly related to component manufacture.

Dissemination of information respecting research is equally unsatisfactory. There is no central agency that collects information respecting all research, digests it, and makes it available to the field. The result is that we do not really know what is going on, where work is being done, and what the gaps are.

Our government efforts at building research are small and scattered. European governments, whose countries have much smaller building programs than ours, have centralized building research agencies with larger budgets than ours. One Japanese building firm has a larger annual research budget than the principal United States government agency carrying on building research.

This is not a plea for all research to be carried on by the United States government, but it is notable that the very large research programs that have made possible the advances in space, defense, and agriculture, to mention only a few areas, have been supported by government funds. In those important areas that do not justify privately supported research, government should step in. There should be a well-organized central research facility that carries on in-house research, collects and disseminates research information, and supports well-coordinated research at universities, private research agencies, in appropriate industrial facilities, and by other government agencies. It can assist in the work of standard-setting and code-writing organizations. It should in short, act as a focal point for the encouragement of research, without itself preempting the field.

From the foregoing discussion it should be clear that building technology is uneven, relatively advanced in structures and envelope, but still requiring considerable improvements in integration of all systems and subsystems, especially the close coordination of all aspects of environmental control with structure. In a general way, the routes that should be taken for improvement are discernible, but the advances possible are not yet off-the-shelf items. They will require much research and development before they are ready to incorporate into buildings.

Building technology is not independent of nontechnological con-

straints rooted in social, economic, and political factors; it is strongly sensitive to and deeply influenced by them. Only if those constraints are taken into account can building technology make its full contribution. The full potentialities will not be realized unless all segments of the building field are determined to find solutions and put them to use. No one segment alone can accomplish it