Proceedings of the National Academy of Sciences
Vol. 67, No. 2, pp. 861–876, October 1970

Recent Technological Developments in Industrialized Production of Housing*

T. Y. Lin and S. D. Stotesbury

DEPARTMENT OF CIVIL ENGINEERING, UNIVERSITY OF CALIFORNIA, BERKELEY, CALIFORNIA 94720

Contributed to Symposium on Aids and Threats to Society from Technology, April 29, 1970

I. Introduction. The industrial and technological imperative production versus construction: In thirty years, 100–200 million additional Americans will be occupying the fifty United States. 85% will seek to locate in the twelve largest metropolitan regions. There will be a need to construct some 300 "new towns" of from 50 to 500 thousand population in order to intelligently accommodate expanded Environmental needs. These 300 new towns would still only provide for 30% of the population increase.

Thus, if each person at today's population represents one unit of Environmental demand, thirty years hence 1.5–2.0 equivalent units must be met just to maintain present Environmental conditions.

The near doubling of our consumer population is to be accommodated, it seems, from a National building productivity base capable of quantitatively meeting less than 50% of existing housing demand[1]. What's more, even if today's productivity were adequate, needs would not be met because average dwelling costs are nearly twice the ability of 50% of home seekers to pay. In the last three years alone, costs have risen an average of 22%; in the last ten years, nearly 35–40%.

In response, President Nixon has called for new "Architectural Forms... Construction Techniques...Financing Methods" to affect better Environmental Design, greater productivity including better quality, and importantly, easier means of purchase (hopefully at lower effective unit costs). HUD Secretary Romney has been assigned the task of meeting these needs. He has stressed Industrial Organization of Construction and related fields, including correlative mass productivity as being essential to success. Neither exists at a significant scale in America today.

America has trailed Europe in the development of industrialized housing systems: It can be seen that the American Construction experience has been in direct contrast with that in Europe following World War II. The late 1940's and all of the 1950's found the United States amply supplied with labor, capital, materials, land, and what are now seen as functionally anarchic general attitudes which glorified short-range planning at a myopic localized scale. On the other hand, Europe was responding to post-war needs which were based on depleted productive capacities in terms of labor, materials, and available capital in combination with the paramount need to house and support general societal recovery of a war-weary urban population. As one extreme example, the siege of Leningrad killed some 80% of that city's construction labor force, in addition to causing great material destruction.

Responsive government leadership financially sponsored and actively helped organize industrialization of the existing building "industry" as a necessity rather than an option. In 1968, more than 1,100,000 industrialized housing units were produced in Europe comprising an average of some 40% of all units built.[2] This year the U.S.S.R. is scheduled to erect close to 3 million units total, some 50% of which is to be factory produced. In fact, it is estimated that currently 25% of all European construction put in place is with industrialized building methods.

Only in 1968 did the United States Congress, through the Housing and Urban Development Act, recognize the need by 1978 for 26 million new housing units as being incompatible with existing construction capacity to produce. This goal outstripped the past ten year production average of 1.3 million units by two to one. In addition, 6 of the 26 million units are expected to be of a low-income type. Today, two years later, annual productivity is still at 1.3 million, and thus, nearly 3.0 million are needed each year to meet the stated goal.

Reports generally support industrialization: Recently, there have been numerous studies and reports, and a few small experiments, concerned with finding a solution to our dilemma. Thus far, results have been more promissory than substantive. The U.S. total of fully industrialized housing in place today (excluding mobile homes) amounts to only a few percent of annual housing production. "Packaged" homes account for about 10% of the annual supply, but these are primarily "shells" requiring much on site finishing, installation, and erection.[3]

The well-publicized Kaiser Report (The President's Committee on Urban Housing—"A Decent Home," 1968), and a less well-publicized Battelle Report ("The State of the Art of Prefabrication in the Construction Industry"—sponsored by The Building and Construction Trades Department, AFL-CIO, 1967) found that applications of technology to improve conventional building methods have been accumulating for some time. Further, the overall supply of labor was held to be sufficient to meet the demands of the construction industry through 1975. In general, the products associated with these constructional improvements were recognized as of good quality, especially as compared to other national standards for amenities per dwelling unit. Hence, it was foreseen that industrial technologies would only accrue as an evolutionary process over a long period rather than as a revolutionary shift away from conventional practices.

These findings seem strangely in contrast with the majority of reports which view the combination of high costs, low productive capacity, and incongruous housing priorities as contradicting the goals established by the 1968 Housing Act and carried further to this date by HUD.[4] In fact, another Battelle Memorial Institute study, this time backed by the Prestressed Concrete Institute, predicted that by 1980 private residential construction will hit $50.8 billion a year, compared with $25 billion today, with 65% being "Systems" built. In total, the systems building market in this same period would grow to $50 billion a year.

The truth of the matter, as always, lies in between the two extremes. So-called "rationalized conventional" methods employing continued technical developments of traditional onsite processes will progress along with a more "revolutionary" development of a highly industrialized Systems Approach to mass production. The inertia of tradition will probably yield to evolved competitive pressures more than theoretical ones. It is clear that in either case, the essential problem is one of PRODUCTION versus CONSTRUCTION whether or not one can agree on the primacy of industrialization versus a continuing conventional organization of the construction "industry".

Industrial technologies are based on mass production goals: The specter of inflation coupled with deficient productivity has now made it difficult for even middle-income families to exercise options considered traditional in the past with respect to either family mobility or expansion in housing needs. It is enlightening to realize that one can purchase eight automobiles for the cost of one detached dwelling as now constructed in the United States (average mortgages are between \$27 and \$35 thousand). If just one automobile were built using methods comparable to a conventionally constructed home, it would cost on the order of fifty times the mass production costs.

At present, some 2,900,000 construction workers (just 3% more than in 1966) have increased their productivity at an average rate of only 0.4–1% a year per worker for the past ten years. For the economy as a whole, the increase has been 2.5% per year per worker. A recent survey by Owens-Corning Fiberglass may even indicate an actual decline in the number of workers employed in construction. They cited that on the average, in seventeen cities studied, it took from one to six weeks longer in 1969, as compared to 1968, to construct conventional housing. A big factor was found to be insufficient labor. By projecting the congressional demand for 26 million housing units for 1978, this country must have some 4.5 million construction workers by that time, but the present growth rate can produce at best only half the needed additional workers. It is clearly improbable that such conditions will obtain much longer without the inauguration of serious industrialized production practices nationwide.

Tradition resists change: There have been many contributing factors to de facto resistance by the construction "industry" to a natural evolution to industrial technologies comparable to almost every other major industry in the U.S. Whereas small-scale private enterprise was successful in 19th Century carriage making, it inevitably had to give way, in a 20th Century context, to mass production of automobiles. The contemporary construction industry has maintained an anachronistic segregation of interests, a stratification of organization, a stultifying multiplicity of local governmental regulations and a disastrously decentralized planning and development approach to the construction of housing when compared with the American society's rapidly changing urban needs. Surely all participants can now see that there will be an adequate supply of work and remuneration if we industrialize to meet both the critical housing needs and those for supplementary urban facilities which must be simultaneously produced. Indeed, we now find ourselves faced with a clearly defined problem, met by Europe in the late 1940's, that existing methods simply cannot quantitatively or economically meet current needs, much less those of the future. PRODUCTION must succeed CONSTRUCTION as a basic approach; it makes good business sense for all participants to rationally foster the change.

II. Major Areas for Potential Savings Using Industrial Technologies. ***A.* Major production–cost areas for savings (the "hard" technologies):** The reare six immediately visible general areas of advantage in utilizing industrial technologies to achieve mass production of housing:

1. economies of scale,
2. economies of labor utilization,
3. economies of productivity in time,
4. to a small degree, economies of material use,
5. prefabrication of key, high-cost components, such as bathrooms, kitchens and utility areas,
6. maintenance and performance-quality.

Those efficiencies which can be allocated to the first four items have been predicted to bring production-cost reductions ranging from 20 to 40% per dwelling unit.[5] However, current European cost analyses have verified only a 10–15% average construction cost savings. This is probably due to the lack of real large-scale production, lower European unit labor costs, and the exclusion of allowance for productivity as related to both financing and early utilization of facilities (between 40 and 50% savings in production time is currently being realized). It will be helpful to discuss briefly each of the major factors:

1. Scale: HUD initiated a Consolidated Supply Program (CSP) for local housing authorities in fiscal 1969. Through economies of large-scale purchasing, they were able to save some 20% in cost of materials. This is typical of this kind of an economy. A mobile home producer can buy large volumes of lumber at $85/1000 board feet as compared to $125/1000 for a conventional contractor. In addition, large-scale construction operations involve "assembly line" repetition of activities. In this case also, economies of a few or several percent can accrue.

2. Labor efficiency: Factory production versus onsite construction: A study conducted in 1968 for the Reston Low-Income Housing Project based its comparison of conventional construction labor costs on those of mobile home factories. It was claimed that the labor: material cost ratio in the factory was 1:8, whereas in conventional construction, it was 1:1. Other studies have shown that Europe has been able to reduce total man-hours per 1000 square feet produced from 1900 to about 900. Conventional construction in the United States averages about 1400 man-hours, and has been projected by Guy G. Rothenstein to be reduced to 800 man-hours with only 500 allocated to onsite labor.[5] He additionally found that in conventional practice some one-third of the labor time is spent in material handling and transportation for some 320 man-hours. In systems building, only about 300 factory man-hours are needed to fabricate an entire dwelling unit.

3. Productivity in time: In a few cases, productivity has been startlingly demonstrated to be of great value. In 1968, the H. B. Zachary Corporation utilized a Systems Approach to produce the Hilton Palacio del Rio Hotel in San

Antonio, Texas at a premium of 20% above conventional construction costs in order to facilitate a 40% savings in construction time. Thus, the hotel realized earlier returns and lower construction financing costs sufficient to justify the increased production cost. With large-scale production, as compared to such a one-time utilization of this approach, the premium cost could at least be eliminated, and probably more sizable savings would accrue. A research project carried out by the Illinois Institute for Technology Research Institute (IITRI) in 1968 assigned a 3% savings factor due to construction finance interest savings alone for the average five-story apartment building assembled in 40% less time. According to Rothenstein, 1% per month of construction time saved is recommended in projecting productivity savings based on combination of reduced interest cost, overhead, and weighting for early occupancy value.[5]

4. Materials: Whereas in many cases more efficient combinations of components will result in some material savings, this is probably the least important source of economies in production. In the case of European large panel construction, more material must be used to accommodate the shipping and erection requirements. Hence, Rothenstein indicates a total materials economy resultant of only 2%.[5] However, the development of new materials and processes suitable to factory production may significantly change the picture.

5. Prefabrication of high-cost components: It has long been realized that certain components in housing are inordinately expensive to construct at the site. A bathroom constructed in the field can cost as much as $1500 or more. The average mobile home bathroom is reported in a Reston study to cost on the order of $200. An Operation Breakthrough proposal submitted by the Home Building Corporation cited conventional onsite plumbing labor costs to be on the order of $900 per dwelling unit. These would be reduced through factory prefabrication to a $10 "connector" charge. Mass production and prefabrication could probably be able to accrue savings for these components on the order of 30–50%. Other wet areas (kitchens and utility areas, including mechanical equipment installations) can be similarly affected by modular prefabrication of utility core units for subsequent insertion at the site.

6. Maintenance and performance-quality (via integrated component design and scheduling of production-erection procedures): Through the Systems Approach to design, the implied replacement and service characteristics currently envisioned (including mass production, maintenance, performance-quality, and operation costs) can be improved. There are no specific projections available along these lines, yet it certainly can be assumed that savings of a few percent will be added to the total. Transportation costs, factory and special erection equipment costs (heavy cranes cost $50,000–$80,000 each) will be increased. Therefore, the sum of all economies must offset these costs. With volume production this is easily accommodated, but smaller demonstration projects may indicate increased costs.

***B.* Major ancillary areas for savings (the "soft" technologies):** In addition to conventional production cost savings, ancillary areas for potential savings using a comprehensive Systems Approach can be categorized as follows:

1. land utilization and site development,

2. marketing systems,
3. maintenance systems and systems of taxation, and
4. the Holistic End Product (Environmental Quality and User Appreciation).

1. Land utilization and site development costs: Land costs now account for some 25% of the purchase price of a conventionally marketed dwelling and site. This is obviously an easy target for the Systems Approach to realize savings. Traditionally, suburban land developments were of single-family housing densities on the order of four sites per acre. With current "good" suburban land selling as high as $16,000 per acre to developers, the effect is obvious. As stated in the *Forbes* article, "Revolution in Suburbia,"[1] it is now not possible to produce conventional detached housing which will qualify for many of the HUD subsidy programs with land values comprising such a high relative percentage of the purchase price. Therefore, developers have turned to "garden" apartments, attached unit clustering, and townhouse site planning to increase density to 8–12 sites per acre or more.[6] With careful architectural design, Environmental amenities can actually be improved and usable open space increased through such design. Other development costs are for utilities, roads and community services. These can also be reduced as a corollary result of a more compact, comprehensive systems-design approach.

It is also interesting to note that the Urban Land Institute's "Land Use Digest" (Feb. 17, 1969) points out that at least 20% of central city property in "60 major cities is sitting idle on vacant lots...". The "Digest" also notes that "one-third of all private land in the urban centers is in vacant lot form...". At from $5 to $16 per square foot to $100 or $200 per square foot for peripheral and near-central city land respectively, this not surprising since only the lower figures will allow even high-rise apartment block development for profit. Low-density suburban sprawl is limited by huge transportation costs; hence, any increased population is not likely to reverse this trend in land cost-utilization determinants. To ease this problem a Comprehensive Systems Approach is required which must include both Government and private interests.

In 1963, apartments averaged one-third of all housing starts, the remainder being single-family detached dwellings; in 1969, 45% were apartments. It has been predicted that detached starts will drop to 45% by 1972. The other 55% will be divided between "garden" and "tower" apartments, and a large percentage of "cluster" and "townhouse" developments. Howard Moskof, Vice-President for Operations of the National Corporation of Housing Partnerships, predicts that three-fourths of its proposed $1.8 billion joint national-local housing effort will be to produce "garden-type" multiple units. At least for the medium and low-cost housing markets, it would seem that the future is predicted by the planning decision of the builder/developer Herbert J. Kendall in his New Jersey Twin Rivers Community: 5% of the units there are single-family, 60% are townhouses, 15% garden apartments, and the other 20% high-rise rental apartments.

HUD has, by implication at least, encouraged comprehensive developer planning through the Systems Approach to create more efficient utilization of scarce urban land resources. The Home Building Corporation responded with a Breakthrough proposal which indicated that monthly payments for housing could be reduced on the order of from $160 for low-cost housing to $131/month or from $211 for moderate cost housing to $149/month under its unique land-leasing and site development program.

2. Marketing: Financing produces transaction and interest costs which significantly influence the monthly cost of housing as well as the required down payment. A 1966 FHA comparative breakdown of cost factors for the conventional construction of an average house indicates that mortgage interest costs alone were 33% of total costs to the consumer while construction costs were less than 25%.[7] The total down payment is influenced by money market conditions but transaction costs, exclusive of discount charges, can run from $300 to $500 for a minimum 1000-square-foot, conventionally marketed home. On FHA and VA loans, discounting costs alone can run $1000 or more on a $17,000 mortgage. Recently, 7–8 point discounts have contributed to a total financing cost of 42% of overall ownership costs. On December 30, 1969, Secretary Romney raised the allowable FHA-insured mortgage interest rate to 8.5%, thus partially legalizing the effective increased interest rates produced by discounting. It should also be noted that financing costs and purchase costs are related in that a 10% reduction in consumer purchase price will, in general, result in a 10% reduction of financing costs.

3. Maintenance and tax costs: Maintenance costs, including real-estate taxes and insurance, for the average moderate-cost homeowner have been estimated to range from $250 to $750 or more per year. Readjustment of the tax base is not within the immediate control of a Systems Approach. However, development of land-rental, homeownership systems, and more efficient site developments in a comprehensive urban context may affect these costs in the long run. Certainly centralized utility systems of distribution and billing, as well as property maintenance systems, can be included. It is, therefore, only possible at this time to consider the possibility of lowered maintenance costs for utilities, appliances, painting, plumbing and electrical repairs, and property maintenance.

4. The Holistic end product (Environmental quality and user appreciation): User appreciation of overall environmental quality may reflect significant indirect economies. John P. Eberhard, in his "Technology Review" article "Man-Centered Standards for Technology"[8] called for the early development of such evaluation standards for the application of technologies. In a manner of speaking, this area represents a frontier of development in the Systems Approach. Identification of economies in this area may, in the long run, be most important. It can at least be surmised that a society which is generally satisfied with the quality and performance of its habitation will also be a more efficient society to maintain.

Summary. A total systems approach is required for optimum effectiveness: It can be seen from the above that a combination of "hard" production-cost economies and "soft" ancillary cost economies may indeed result in a potential for savings on the order of 25–30% under conventional consumer costs for housing. To accomplish this, a far more comprehensive Systems Approach to PRODUCTION must replace the conventional CONSTRUCTION approach to design, component fabrication, building erection, marketing, and management of large development projects. The government will have to play an important role as both advocate and financial supporter if such is to be realized in the near future. Hence, it can be seen, a vertical integration of overall industrial organizations would greatly facilitate the economic operation of any Systems Approach to mass production of housing. "Hard" technologies, while probably being the most important physical enabling factor, will not accomplish the task alone. Indeed, these technologies have existed for 10 years (although in need of development and refinement) to produce the quantity and quality of housing needed between now and the year 2000. The overdue development of the "soft" technologies is now requisite to preserve the quality of Environment we are experiencing today, and hopefully to improve it for all of our citizens of the future.

III. The Basics of Industrialization and Systems Building As It Exists Today. ***A.* Basic requirements for industrialized production:** There are three essential requirements for economical utilization of industrialized technologies of mass production: (1) repetition of factory process (as of now, in-production alterations are expensive), (2) automation, or at least a highly rationalized Systems Approach to both in-plant prefabrication and onsite erection processes, and (3) in order to justify the required initial capital investment, year-round production at near-optimum plant utility must be guaranteed through the aggregation of large predictable consumer markets.[9] Currently, about 90% of single-family housing builders erect fewer than ten units a year. Levitt and Sons, the nation's "rationalized conventional" home building "giant", produced 6800 units in 1969.

It is estimated that an efficient factory approach to the production of housing would require annual demands of from 1000 to 5000 or more units per year for five years to amortize the $1.5–$2 million cost of a typical Large Panel System offsite factory. In addition, transportation restrictions limit the factory market distance to 300 miles, with about 50–100 miles the optimum. A smaller onsite factory which might require somewhat less annual production can be established with $300–$500 thousand. Therefore, aggregation of large markets will require a great deal of coordination between those interested in developing housing projects and those interested in investing in factory facilities.

It is also important that onsite assembly and installation labor requirements be reduced to a minimum since these unit costs are among the most expensive in the whole construction process. This requires thorough preproduction design and efficient scheduling of fabrication and erection activities.

Pursuant to all of the above, government leadership and support at both financial and negotiating levels must serve a sustained catalytic function to achieve integrated development of efficacious industrial plant and marketing organizations. This must be accomplished at a massive scale, equivalent to, if not greater than, other areas of national support such as for NASA, Agriculture, or the Defense Department. Unfortunately, the precedent for this action is discouraging. Governmental allocations for research and development in *all*

HUD areas in 1966 were less than 1% of allocations for research and development in Agriculture alone. When it is considered that Americans spend some $100 billion each year to build, buy, rent, furnish and maintain homes, the consistent lack of substantive Federal commitment to influence achievement of equitable national housing priorities is strange indeed.

An architectural design challenge: Equally imperative along these lines is support for the attainment of all the above goals while simultaneously providing for optimum Architectural design flexibility in utilizing mass-produced Systems Building components. The redundant production of stereotyped apartment blocks (recently criticized in Europe) is not sufficient for America.

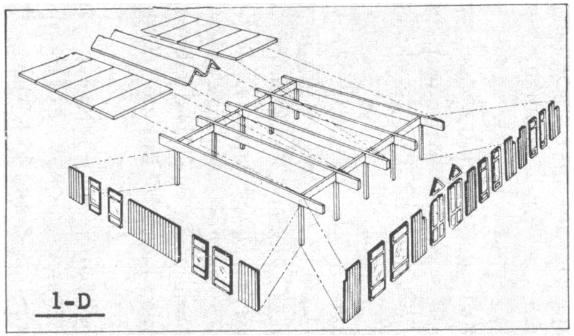
***B.* Prototypical categories of building systems for housing production:** One, two, three and four "dimensional" building systems such as the respective frame, panel, modular cell and performance componentized versions (Fig. 1) have been recently emphasized in the U.S. as generic to industrialization of the housing construction "industry." These are but products of a comprehensive Systems Approach, yet each has characteristics affecting component design, fabrication, erection requirements, and architectural design flexibility for creation of "decent" housing Environments. In the past, a distinction has been made between proprietary (closed) complete systems, now prevalent in Western Europe, and universally standardized (stock-order or open) systems, until now most popular in the U.S.S.R. A brief discussion of each system type follows:

1-D: One-dimensional (frame) Systems such as the U.S. Neil Mitchell Frame System are apparently most efficient where unskilled, onsite labor is to be utilized to some advantage. It is most analogous to, though much more sophisticated than, conventional construction practices using precast components. Infill floor and wall panels are used to complete the enclosure; Mechanical Subsystem assemblies may be installed. Architectural flexibility is considerable. Thus far, no frame housing system has been embraced in a significant way by either Europe or the U.S. largely because onsite labor requirements are considerable. Generally, these systems require only conventional erection equipment and joinery techniques.

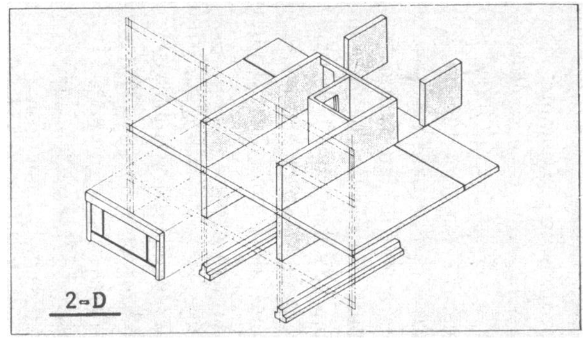
2-D: Two-dimensional (panel) Systems are by far the most popular of the four prototypes developed to date. They are of two basic types: Small-Panel and Large-Panel Systems. In Europe, the Large-Panel System has been developed such that it dominates Systems applications.[10]

1. Small-Panel System: The Small-Panel System utilizes modular dimensional limits on the order of four foot width by room height for lightweight handling and assembly flexibility. Hence, it takes a larger number of these panels to fabricate a building than would the Large-Panel System. Though Architectural flexibility is achieved, as would also be expected, joint continuity requires careful design and considerable site labor. Where maximum use of unskilled labor is required, as with the one-dimensional systems, this may be an advantage. Conventional erection equipment is used.

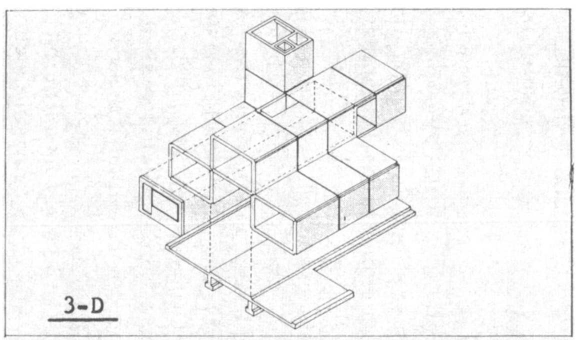
2. Large-Panel Systems: The large floor or wall panels may range in size from that of a single room to some 60 feet in length encompassing a suite of rooms. They are usually one-story in height but they can be taller and less wide. In



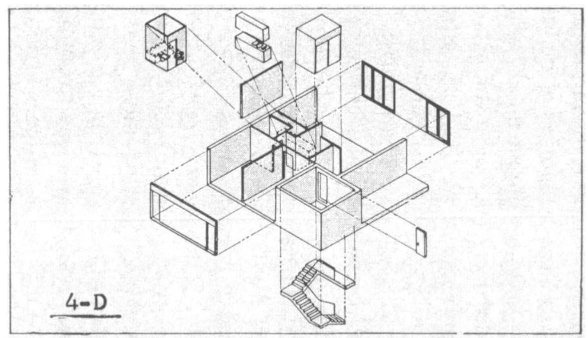
Post and Beam (Frame): Usually consists of prefabricated columns and beams with panels of either structural or nonstructural function. Components can be light enough for installation by men.



Panel or Slab: Panels are of precast or cast-in-place reinforced concrete with other components cast into the slab in varying degrees of complexity. Design may be load-bearing, cross wall or core-bearing.



Box: Takes various forms—component, assembly or complete subsystems—but always the structural element is a prefabricated three-dimensional space-enclosing unit of small, intermediate or large size.



Performance or Componentized: Components result from performance specifications that also decree full compatibility of the subsystems. This system allows rearrangement of interior space.

FIG. 1. Basic types of building systems. Source: *Engineering News-Record*, Special Report (Oct. 30, 1969).

Europe concrete wall panels average 6–7 inches in thickness. The weight of the average large panel can be ten or more tons, thus imposing the requirement for heavy equipment to assemble buildings. At the same time, onsite labor is reduced relative to the small-panel system because of the smaller number of panels and joinery problems. Postproduction Architectural flexibility must be carefully pre-designed for optimum advantage.

3-D: Three-dimensional (Modular-cell) System. In the U.S. and recently in Russia, development of systems building has progressed to that of assembling volumetric modules which have been factory prefabricated, thus bypassing the frame through the panel systems. These may consist of three walls, a roof and a floor, two walls a roof and a floor, or any self-supporting combination in between. They are at best fully finished with all furnishings, utilities and surfacing in place on delivery to the site. Only the erection-placement and service connection of the modules is required to complete the assembly of an entire building. They are, as might be guessed, considerably heavier (in normal reinforced concrete systems) than the large-panel system components. Moshe Safdie's Expo '67' Habitat concrete modules weighed 80–95 tons; his current Habitat Puerto Rico modules, 22 tons. Special heavy erection equipment is required. In addition, the module bulk imposes transportation constraints as to both the number of components which may be delivered per vehicle as well as to the dimensional limits of the modules. On the other hand, site work is reduced to an absolute minimum, erection of a large building being easily accomplished on the order of one-half the conventional time period or less. Architectural flexibility must be achieved at a volumetric scale of assembly. In the U.S. and recently in Russia, most of the development work in systems building is utilizing the modular cell approach.

4-D: Four-dimensional (performance componentized) Systems represent a conceptual shift from that of manipulating a preconceived dimensional component such as the frame, panel or modular box to that of supplying to manufacturers very detailed sets of performance specifications for essential component requirements as compatible subsystems. The manufacturer is then left with the option of proposing any product subsystem which will meet these performance requirements. Thus, the 4-D system may consist of an assembled combination of dimensional approaches to component subsystem design. The usual requirement is, therefore, for 100% potential interface compatibility between all subsystems. In this way, a somewhat "open" system is achieved since one could order compatible components from independent manufacturers. This only has an advantage in that exploitation of individual producer ingenuity is emphasized. On the other hand, it is also quite cumbersome and time-consuming, and the design of adequate specifications requires sophisticated methods and uncommon competence at today's level of overall Systems development. For example, the Toronto (SEF) School system, patterned after the American School Construction Systems Development (SCSD), found it had produced 50,000 possible interface combinations of the five basic sub-systems. These had to be analyzed for the purpose of extracting optimum combinations. Since that time, attempts to implement the system have produced construction costs savings of up to 10%, though this is apparently subject to interpretation according to some current reports. The impending University Residential Building System (URBS) developed by the designer of SCSD, Architect Ezra Ehrenkrantz, has been more than three years in development and has yet to initiate construction. It is also interesting to note that the precast concrete bid winner for the structural-ceiling subsystem recently closed its California plant, thus further delaying the project. The predicted economies are on the order of 8%.

Summary. It is felt that these four prototypes represent first generation Systems Approaches. It is most likely that the 2-D and 3-D systems will dominate development in the near future. These will, however, be used in combination, rather than in strict singularity, such as by combining the large panel and prefabricated modular utility core systems to achieve maximum Architectural flexibility and optimum overall benefits from the Systems Approach. It can be visualized that development begun by Paul Rudolph and Moshe Safdie will continue wherein multi-story frames and corridors may be prefabricated and post-tensioned together with prefabricated 3-D units being inserted into the frames. Also lightweight 3-D units can be lifted by helicoptor, stacked in various arrangements, and inter-connected to form high- or low-rise housing. As was the case in Europe during its earlier years of development, of the estimated 300 systems approaches which have evolved in America over the past seven years (236 "full housing Systems" applications were received by HUD for Operation Breakthrough) only about 10% will be expected to survive at any significant level. These will be developed largely on the basis of successful empirical experience, and hopefully with strong governmental financial backing, as well as preferential treatment, as was also the case in Europe.

IV. Operation Breakthrough. The Federal Government response to our urgent housing needs has largely been focused in HUD's Operation Breakthrough program. Secretary Romney described Operation Breakthrough as

> "... not a program designed to see just how cheaply we can build a house, but a way to break through to total new systems of housing production, financing, marketing, management and land use.
>
> "Breakthrough supports the development of new and innovative housing system concepts and production methods, better management and maintenance methods, broader financing opportunities, prototype construction, and testing and evaluation. It also seeks solutions to many problems impeding large-scale production of housing such as inadequate assembling of land, restrictive zoning and building codes, inadequate financing, inefficient use of labor forces, and time-consuming complications in legal procedures."

And in recognizing that this one program could not do the job alone, he cited the need for a "stable supply of mortgage capital, and the policy changes necessary to accomplish this and other improvements in the housing business." The methods employed are largely persuasive with a minimum amount of federal subsidy being allocated by Congress to support the design and production of some 3000 prototype units on 11 sites scattered across the U.S. The Projected government commitment is some $66 million as compared to the $100 billion spent annually by Americans for all associated home ownership or rental costs.

Thus, HUD's current housing research and development expenditure amounts to less than one-tenth of 1% of this annual expenditure of personal income.

It must be said that Secretary Romney, Assistant Secretary for Research and Technology Harold Finger, and Breakthrough Director Alfred Perry all have been outspoken on the need for subsequent large expenditures of federal money, if we are to achieve our stated housing goals by following through on the promising Breakthrough beginning. With the money on hand, it appears that Breakthrough has thus far been successful in that more than 236 complete (Type A) systems and 385 research and development (Type B) proposals were received seeking to take advantage of government backing. Twenty-two winning Type A proposals are going ahead; the Type B awards are yet to be made. If, however, the follow up is not at a much larger scale, it will be doubtful that current conditions will be mollified; they may even be exacerbated.

The result of breakthrough awards in brief: The physical appearance of the Building Systems chosen for prototype construction is, by and large, conventional "to contribute to current marketability and consumer acceptance." Seven of the 22 selected are of concrete, 6 rely on wood primarily, 5 use metal framing as a wood substitute, 2 use plastic foam in panel sandwich cores, and 2 use plastic fiberglass materials and onsite factories. The scarcity of wood, the relative abundance of concrete, (and to a lesser degree steel), and recently developed structural plastics were indicated in materials usage.

The two most technically innovative systems for future influence on Architectural design are: TRW Inc., and Material Systems Corporation, fiberglass modular systems. TRW produces 3-D modules from winding fiberglass reinforced panels on a mandrel core. Material Systems Corporation produces simulated surfaces on plastic panels by spraying fiberglass on special molds.

The Keen System, which is predicated on a combination post-tensioned concrete superstructure frame with modular inserts to generate "artificial land" in space, is primarily designed for dense urban renewal projects and use of air rights over existing sites. The Keen System can be held to be the most significantly indicative of potential innovations in comprehensive Architectural Systems design. This is due largely to its combination approach (which includes "foundations") as contrasted to the more common adherence to a single prototype conceived at a single unit scale. National Homes also uses a large-scale frame and modular insert system, but it is primarily derived as a post-tensioned concrete high rise structural frame supporting 3-D modules to form apartment towers.

Other factory prefinished modular systems are comprised of various degrees of physical innovation in concert with less visible production advances. For instance, the Scholz Homes system consists of a highly rationalized and fairly automated factory produced sectional module using conventional wood framing which, when completed, appears as any other electrically stylized suburban housing. The Shelley (post-tensioned concrete 3-D) Systems is comprised of simple boxes assembled in a checkerboard elevation with voids serving as bonus living space to be finished onsite in a fairly straightforward manner. Levitt Technology and Christiana Western Structures, Inc., have developed elaborate semi-automated 3-D wood module and panel fabrication assembly lines respectively. G. E. can cast a 30′ long fiber-reinforced plaster panel which is crack resistant. Pemtom, Inc. produces room-sized polymer-bonded plywood modules which are so rigid as a whole that they may be fully cantilevered without additional support. Hercules, Inc., has developed a metal high-rise frame system around which lightweight concrete can be poured. The frame acts as both form and reinforcement. Paper honeycomb core sandwiches are used by both G. E. and TRW for floor, wall or ceiling applications. Ball Brothers uses a polyurethane core to produce similar plywood "stressed skin" panels.

There are two French (Tracoba and Balency MBM), one English (Wates, L.), and one Canadian (Descon/Concordia) Large-Panel Systems which have been slightly modified. European usage has been primarily for high-rise apartment buildings. The Henry C. Beck Balency (U.S.) System, is a good example with proposals for low density and one-story through high density apartment block applications. These are all generally conventional in appearance with innovations primarily arising from systems of prefabrication and assembly, as well as economies of scale, and speed of erection rather than from radical Architectural design import.

Mechanical "hardware" innovations of significant design note are few with National Homes alone advocating a water-conserving, vent-pipe eliminating, (Swedish) vacuum sewage disposal system which could be installed community-wide. Additionally, the concept of dividing "black-water" and "gray-water" waste systems has been suggested for overall community use. Home Building Corporation, one of two successful bidders not adopting the consortium approach, has proposed development of sites using street offset utility trenches with layered service distribution according to frequency of maintenance. In general, all the winning systems use prefabrication of plumbing, electrical, and HVAC services in either utility panels or volumetric cores vertically stacked.

Summary. Coordination of overall and component design determinants, including those of factory production and site erection, is the basic departure from conventional CONSTRUCTION oriented methods. It is significant to note that Levitt and Sons (through Levitt Technology Corp.) as the largest "rationalized-conventional" builders have proposed a fairly completely industrialized wood 3-D System. National Homes Corporation, having sold 10,800 primarily "package type" manufactured homes in 1969, has also opted for a metal stud 3-D Systems Approach. Further development and experience will evolve more comprehensive and genuine industrialized Systems Approaches to housing production. This is a good beginning but as such it must be adequately nurtured and quickly expanded to achieve real mass PRODUCTION.

VI. Summary. Where Do We Go from Here? Private enterprise is interested: Private consortiums had initiated development of a Systems Approach to housing production even before Breakthrough. One notable system is the Sepp Firnkas Large-Panel System designed originally under the trade name of TechCrete by Architect Carl Coch in collaboration with Engineer Sepp Firnkas. Since its introduction in about 1965, more than 2000 dwelling units have been constructed with this system. Omniform, a "total" Systems consortium, also utilizes the Firnkas system. Jones and Laughlin Steel Corporation, along with Donn Products of Cleveland, have formed Jal-Donn Modular Buildings Incorporated to produce all-steel apartment house modules. The Stanford Research Institute under a $1 million study financed by Olin Mathieson, Northern Natural Gas and other U.S. corporations together with Jonathan Development Corporation developed two types of factory produced housing concepts. These will be used in a $21 million HUD supported "new town" development named Jonathan, Minnesota to accommodate 50,000 persons in 20 years. Initial construction will involve 500 units. The U.S. Steel Corporation has developed a modular hotel room system for 1,450 6-ton units at Walt Disney World now under construction near Orlando, Fla. C. W. Blakeslee and Sons, Incorporated has obtained the U.S. franchise for the very successful European Bison Wall System. This same system will apparently be incorporated in the plans of Precast Systems Incorporated recently formed by 40 existing producers of conventional precast concrete building elements to tap future markets. In all, some 8–10 European and Canadian systems have been franchised to U.S. producers or consortiums.

Boise Cascade, utilizing its own expertise in mobile home production (adapted to "sectional" housing for Breakthrough), has determined that it will spend $250 million to develop 250 mobile home communities fully developed to include community recreation facilities analogous to many more expensive suburban developments. This is spurred, no doubt, by the fact that mobile homes accounted for 450,000 dwelling units produced last year serving 90% of the under $15,000 home sales. Freuhauf, truck trailer manufacturers, have decided to enter the modular home production market. Moshe Safdie is currently involved in a 800 unit 3-D post-tensioned concrete development now under first phase construction in Puerto Rico. Stresses Structures Incorporated of Denver, Colorado, producers of the 1967 Richmond, California "Uniment" demonstration project (Precast concrete modules with 2" thick walls) have license negotiated with a Canadian company, Polymer Corporation Ltd., for licensed use of their expansive cement process.

State governments and unions are acting: In addition, California, Ohio and New York have all enacted new legislation designed to stimulate factory production and housing by overriding local code restraints where necessary. Washington State is in the process of drafting similar legislation. Detroit and St. Louis trade unions are negotiating apparently agreeable contracts with producers of factory-built dwellings. In December, 1969, the National Housing Corporation for housing partnerships filed a registration statement with the Securities and Exchange Commission for a $50 million offering of securities. The Corporation has negotiations under way for construction of about 3000 housing units in 15 cities and hopes to have arrangements made for another 4500 a year from now.

Mobile homes are recognized: President Nixon has announced that he will (for the first time) include the 450,000 units of mobile homes being sold in 1969–70 in the national housing productivity figures, thus raising the total from 1.3 to 1.75 million units per year. In addition, Secretary Romney has now provided for FHA-insured mortgages on mobile homes. It is quite possible that the Mobile Home Industry, being a major forerunner of factory housing production, would eventually play a significant role in the Systems Approach to housing as a whole.

Aggregation of predictable markets and a national building code may be the

key: Federal and State governments must play a large role in persuading local authorities to assist in the aggregation of markets sufficiently large to support the initial private investment required for factory facilities. Though the technological basis for housing production already exists it needs integrated developmental programs to eventually realize significant economies and to improve environmental qualities. Necessary efforts can be mounted to achieve a total Systems Approach, including design, production, financial, marketing, social-humanistic, labor and organizational aspects. The critical bottleneck at the present is the lack of guaranteed continuity in market volume which is required for profitable industrialized production. To turn this historical corner from diversified CONSTRUCTION to centralized PRODUCTION of housing, our Governments must play a massive leading role.

The government can also use its persuasive influence in awarding federal grants to localities which cooperate to bring about acceptance of a uniform building code for the entire nation. It should be noted that code idiosyncrasies are not so important as is national consistency. A national code should be performance oriented where possible with provision for early testing and uniform approval of innovative materials, methods of assembly and completed systems. Breakthrough is already attempting on a small scale to accomplish this.

Finally, the U.S. construction industry as a whole should benefit from European experience by avoiding over-emphasis of large-block apartment production. Instead we should emphasize mixed-density developments including low and high rise Systems Building applications in concert with comprehensive Environmental design and land development planning. A combination of private enterprise efforts adequately supported by various forms of government subsidy will have an important catalytic effect by fostering early realization of the potential for high-quality and economic mass production of homes in "decent" urban environments. In some cases, direct "first" production costs should even be allowed to exceed conventional costs through use of incentive subsidies. Large federally controlled or regulated "new town" projects which could completely waive local code and labor restrictions could even revolutionize U.S. housing production.

* **Note.** The article printed here is an abbreviated version of the talk presented at the symposium. The complete version, which includes 12 figures, two appendices, and an extended bibliography is available from the authors on request.

[1] *Revolution in Suburbia*, ed. Forbes (New York: Forbes Inc., April 1, 1970).
[2] Systems Building (Special Report). *Engineering News-Record* (New York: McGraw-Hill, October 30, 1969).
[3] Report of the President's Committee on Urban Housing (Kaiser Committee): *A Decent Home* (U.S. Govt. Printing Office 0-313-937, 1969).
[4] Bender, R. C., *Selected Technological Aspects of the American Building Industry* (prepared in 1967 for the Douglas Commission on Urban Problems). U.S. Dept. Commerce; Natl Clearinghouse for Federal Scientific Technological Information, Pubn. PB 185211.
[5] Rothenstein, G. G., *J. Prestressed Concrete Institute*, **13**, 33–40 (1968).
[6] Hanke, B. R., *Civil Eng.*, **39**, 49–52 (1969).
[7] Based on 1966 data for FHA insured, 20-year financing, owner-occupied, single-family house.
[8] Eberhard, J. P., *Technology Review*, **71**, 51–55 (1969).
[9] Schryver, P., *J. Prestressed Concrete Institute*, **14**, 54–61 (1969).
[10] Koncz, T., *J. Prestressed Concrete Institute*, **14**, 53–63 (1969).