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Housing and Building Technology in Developing Countries

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For
Beverly, Diana, Joan,
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1

Introduction

Economic development can be called a process that makes most things a little better and housing a lot worse. No one objects to improving insalubrious housing unless replacement would blatantly aggravate unemployment or poverty. Some writers have favored postponing housing investment and bearing with nasty shacks and squalor until factories, roads, warehouses, and dams are abundant. These are supposed to make everything else easier. Another school, by contrast, sees no conflict and asks why the unemployed cannot be mobilized to build solid houses as easily as shacks.

This quarrel cannot be resolved without bringing in technology, which in the housing sector, as in others, has played both an active and a passive role. The passive role lies in the spectrum of options conventionally available and brought into play when there are shortages, real or contrived, that is, when relative wages and prices change. The ease of bringing these options into use is called the elasticity of substitution, and one chapter and two appendices in this volume deal with it. After establishing many qualifications, the elasticity is found to be substantial, meaning that building will stay labor intensive as long as wages are relatively low. A more general issue is: If adequate technology were widely diffused, housing would be good, productivity would be high, and the unemployed would have jobs. But what is "adequate"? Does it exist? Can it be invented? This study probes the role that building technology has played in recent years. The chance for better performance will be deduced from this record.

Housing in Development

Rather than anticipate details, this Introduction attempts to put the role of housing construction in development into general perspective. With adequate or even extremely appropriate technology, what may be expected of housing construction in development has its limits. The pressure to tackle nonhousing problems with housing and non-technological problems with technology is great if housing and technology are all one knows. If the housing sector has grown in a certain way in the past, even the best technology will not make it depart too far from a pattern that probably reflects more basic social elements. The volume of building may triple or quadruple but will not multiply by one hundred.

When the rural poor migrate to cities, construction often gives them their first jobs, ones that require little skill or a disciplined sense of routine. What skills are learned can be applied to the "informal" sector of building shacks. Apart from migration, all population growth is almost at once converted into a need (if not economic demand) for housing and expanded settlements. Any concern for the environment and ecology must begin with the damage that poorly conceived human settlements cause. Estimates of this damage show that countries cannot really afford to be poor.

In poor countries the most obvious characteristic of construction data is their low quality. Some countries make no estimate for "informal" or noncommercial building, and others report even commercial building for only one or two major cities. Some reports are based on building permits which are only loosely related to building activity. Employment statistics often come from only one or two sample weeks during the year. What follows is an attempt to reason correctly on the basis of these uncertain figures.

Countries with annual per capita products below US$400 (1970 dollars) typically report GDP shares of 2 to 3.5 percent for housing. Transitional countries (US$400 to $1,500) and advanced ones (over $1,500) report GDP shares of 4 to 8 percent. Except for France, the richest countries do not report shares as high as such intermediate countries as Greece, Cyprus, and Puerto Rico. This pattern is not new, derived from one year's cross section, but goes back at least to the mid-1950s, when Japan and Italy were still in the intermediate category.[1]

Time series data and elasticities fit the cross-sectional pattern. The elasticity of housing investment expenditures with respect to gross domestic product from poor to middle income levels is very high: 2.3. During the middle period, housing investment elasticity with respect to GNP seems to be around 1.6. This figure means that whenever GNP grows by one percent, housing investment will grow by 1.6 percent. Within poor countries it is a low .3, and from the transitional to the advanced it falls off to .9. Within the advanced set it remains at 1.3. In terms of annual growth rates (least-squares logarithmic fits), housing grows at 2 percent in poor countries, accelerates to 10 percent at the intermediate stage, and then slows down to 6 percent. The acceleration is due partly to the general economic spurt at middle income levels and partly to the increased migration of people into the cities and the movement of housing out of the nonmonetized, unmeasured sector.

In some countries natural population growth and subsequent household formation also remain high during this period. An expansion of dwelling construction in countries at the $300 per capita income level, even if overdone, remains in line with natural trends and can be no absolute waste if the housing is reasonably durable.

Nothing precisely quantitative about employment and materials production as a result of housing programs emerges from national statistics. These do not distinguish materials and labor for housing from those for other types of construction. Other construction also grows as a share of national product, reaching a peak during the middle income phase, but the pattern is much less pronounced than in housing. The share rises from 5 to 8 percent and then levels off at around 7.5. The corresponding growth rates rise from 4 to 5 percent annually. With wide variations, the share of housing in construction rises from about 30 percent to 40 percent.

All of these figures abstract from the fluctuations that characterize construction. According to a study by Thomas Edens, nonresidential construction fluctuates in phase with balance-of-payments reserves in poor countries and out of phase in advanced countries. Housing does the reverse, but being the smaller component it does not determine the net effect for the construction sector.[2] Apparently, nonhousing construction is affected by recessions (export declines) in poor countries, but is used counter-cyclically by the advanced. On the other hand, loss of income and nervous credit institutions reduce housing starts at such times in most rich countries. With less integrated financial institutions, housing in most poor countries is less sensitive to these disturbances.

Expenditures on building materials naturally follow a path similar to expenditures on construction, rising from about $6 per capita per year to over $100 in advanced countries. Moreover, Hollis Chenery and Lance Taylor have found that, as a share of GNP, nonmetallic manufactured mineral products reach a peak around per capita product levels of $700 (1960 dollars) and then fall off by about one-third.[3] Only textiles and rubber products have a similar, although less pronounced, peak. This rise in the transitional stage is partly due to the lag in establishing cement, glass, and various fixtures industries. With most housing remaining in the unmeasured (self-help) sector, one finds that many African countries import 50 to 60 percent of their construction materials, mainly steel and cement. In Asia and the Far East, the import share remains a high 30 percent, but even before the middle income phase starts, the share begins to fall sharply.[4]

Construction workers constitute 2–5 percent of the economically active population in less developed countries and 7–10 percent in advanced countries. As usual, these figures mainly show that poor countries have an enormous agricultural sector, partly subsistence and unintegrated with the rest of the economy. Small countries that feature oil or tourism — such as Barbados, Trinidad, Kuwait, or Bahrain — may reach a figure of 15 percent of workers in construction.

Employment outside agriculture may be a better index of change. Here the share of construction rises from 7 to 10 percent in the transitional phase and then falls back to 9 percent. The average annual growth rates of construction employment rise from one to 5 percent and then slow down to 2 percent.

These changes in employment and output growth are associated with corresponding changes in the average productivity of labor. With many migrant workers available for the sector, productivity can lag and employment can grow disproportionately to make up the difference. The elastic supply of construction workers is perceived as such by construction firms because wages remain relatively low. In the early phases of development, it is hard to enforce labor legislation or to form militant unions in small enterprises that move from site to site. Consequently, hourly earnings typically will rise only at an annual rate of 3 percent (in real terms), compared with 4 percent in manufacturing.

In the transitional, middle income phase, however, the demand for construction workers is such that their hourly earnings begin to grow faster than those in manufacturing, at a 6 percent as opposed to a 4 percent rate. During this period, hourly earnings begin to exceed those of manufacturing — \$0.42 versus \$0.39 (1963 dollars). Japanese construction earnings made the transition around 1960. In nine developed European countries, the margin in favor of construction workers stabilized at 22 percent from the mid-1950s to mid-1960s, meaning that both construction and manufacturing hourly earnings grew at an annual rate of 4 percent. In the United States, construction workers with their particularly militant unions had reached levels 31 percent above the manufacturing average. Although their rate of unemployment was double that of manufacturing during 1959–1967, their negotiated wage increases rose by 57 percent compared with 37 percent in manufacturing.[5]

Insofar as higher construction wages reflect greater bargaining strength instead of higher productivity, appropriate deflation is in order for construction value added and its share in gross national product. Substitution of materials and equipment for on-site labor had already lowered the value added share in gross construction to 35 percent for the United States and Canada, compared with 58 percent for Europe. In poor countries the share was 49 percent.

The 7.5 Percent Ideal

This description of what actually happens may be compared with primitive theories of what *ought* to happen. If in fact few countries have reached an 8 percent share of GDP with housing, the primitive theories are unanimous in deriving 7.5 percent as an ideal. Does this unanimity make sense, or is it due to false assumptions and statistical hanky-panky?

The first primitive theory is the shares approach. It holds, first, that the share of family income spent on housing H_t/Y, should be 15 percent (without land). It assumes, second, that the share of household income in national product, Y/O, is two-thirds. Finally, it assumes that housing expenditures other than maintenance and repair, those on new construction, H_c/H_t, are three-fourths of all housing expenditures. Hence, H_c/O, the logical share of new housing construction in GDP, is 7.5 percent.

$$\begin{aligned}\frac{H_c}{O} &= \frac{H_c}{H_t}\ \frac{H_t}{Y}\ \frac{Y}{O},\\ &= (3/4)\ (.15)\ (2/3),\\ &= 7.5 \text{ percent.}\end{aligned} \qquad (1)$$

The second primitive theory is the target approach. It begins with the widely accepted target that countries ought to build ten dwellings per 1,000 inhabitants per year, $H/P = .01$. Moreover, the target quality for housing ought to be such that three man-years of labor (on site and in the materials) are required to build the average dwelling ($L_h/H = 3$). Finally, it is assumed that 40 percent of the population is in the labor force ($L/P = .4$, $P/L = 2.5$).

With the following equation, one can estimate the share of housing construction and related employment in the total:

$$\begin{aligned} \frac{L_h}{L} &= \frac{L_h}{H}\ \frac{H}{P}\ \frac{P}{L}, \\ &= (3)\ (.01)\ (2.5)\,, \\ &= 7.5 \text{ percent.} \end{aligned} \tag{2}$$

If the productivity in construction and related fields is equal to that of labor on the average, this estimate is identical to equation (1). Payments for land purchased beyond urbanization costs are not included because such transfers are not production and because capital gains are not counted as part of national product. Rent paid on residential land is commonly included in national accounts as intermediate household consumption, but it is left unrelated to investment. Note that if construction workers earn the average wage, only very long mortgage maturities could keep monthly payments down to 15 percent of income for a three man-year house.

Finally, we have the more sophisticated growth-replacement approach. It says the share of GDP spent on new housing depends on the sum of what needs to be replaced because of deterioration, R, plus what needs to be added, A, because of income and population growth. It turns out that $(RO + A)/O = 7.5$ percent.

Replacement depends, first, on the durability of the average dwelling. If 50 years is the average durability, then one-fiftieth of the housing stock must be replaced each year if the stock is not growing. A stock growing at rate g, with life expectancy e, must be replaced at a rate (r), with $r = [e(1+g)^e]^{-1}$. Considering that value, apart from the site, falls with deterioration and obsolescence, a plausible rate of replacement, including repairs, is one-twenty-fifth of the housing stock.

The value of the housing stock is assumed to be 100 monthly payments as a rule of thumb, so that each year's housing payments come to a value of 12 percent of the housing stock, $H_t/S = 12/100$. As in the shares approach, it is assumed that families spend 15 percent of their income on housing (without land) and that family income is two-thirds of national product. With all this, one can deduce that the housing stock by value equals 83.33 percent of national product:

$$\begin{aligned}\frac{S}{O} &= \frac{S}{H_t}\ \frac{H_t}{Y}\ \frac{Y}{O},\\ &= (^{100}/_{12})\ (.15)\ (\tfrac{2}{3}),\\ &= 83.33 \text{ percent.}\end{aligned} \tag{3}$$

If one-twenty-fifth of this stock must be replaced each year, replacement will equal 3.33 percent of national product.

$$\begin{aligned}\frac{R}{O} &= \frac{R}{S}\ \frac{S}{O},\\ &= (^{1}/_{25})\ (.8333),\\ &= 3.33 \text{ percent.}\end{aligned} \tag{4}$$

The remaining housing construction is the growth demand, A, due to more families and higher incomes. If the income elasticity of demand is assumed to be unity, then the share of family income spent on housing will remain 15 percent (or whatever), whether there are more families, or higher incomes, or some combination. What matters is how much the combination of either population growth or rising productivity makes national product grow. Even supply inelasticity will not affect the result in value terms if the price elasticity of demand is assumed to be -1.0, which is consistent with an income elasticity of one and constant shares. The housing stock must grow at the same rate as national product. If that growth rate is 5 percent, the share of national product for the growth demand is 4.17 percent.

$$\begin{aligned}\frac{A}{O} &= \frac{dO}{O}\ \frac{S}{O},\\ &= (.05)\ (.8333),\\ &= 4.17 \text{ per cent.}\end{aligned} \tag{5}$$

If the replacement and growth demands are added, the share of housing construction in national product is once more 7.5 percent. With consistent assumptions, one does get consistent results.

$$\begin{aligned}\frac{A+R}{O} &= \frac{A}{O} + \frac{R}{O},\\ &= 3.33 + 4.17,\\ &= 7.5 \text{ percent.}\end{aligned} \tag{6}$$

All three approaches involve rather plausible assumptions and suggest that those developing countries that are building dwellings not observing and counting everything that is going on, or they have an unexploited opportunity for expanding a key sector of their economies. How big that opportunity is can be learned only by substituting the results of empirical studies for assorted assumptions. Several of the ratios used above could be one-third higher or lower in particular countries and changing over time. The omission of most financial elements, urban land policy, and migration is particularly conspicuous. A fourth approach is one presented in chapter 7. Applied to Tunisia for 1975–1985 by the author, it suggested a 7.6 percent share of gross domestic product as the optimal amount.

Great Builders

As a standard of comparison, one can look at the record of the dozen most assiduous home building nations of the period 1968–1971 (Table 1). The share of all construction labor in employment ranged between 8 and 12 percent. Most of the countries built between 8 and 14

Table 1. *Gross Fixed Capital Formation in Construction and Housing as Shares of National Product and Construction Employment as a Share of Total Employment in Selected European Countries, 1968–1971*

Country	*Dwellings completed per 1,000 inhabitants*	*Persons employed in construction as a percentage of total employees*	*Gross fixed capital formation as a share of gross national product: All construction*	*Housing*
France	9.0	10.4	14.7	8.7
Puerto Rico	9.2	10.8	20.5	7.9
Cyprus	5.4	10.2	13.2	7.4
Greece	13.7	7.8 (1971)	16.8	7.0
Japan	11.9	7.6 (1970)	—	6.8
Italy	6.0	10.4	12.8	6.6
Switzerland	9.9	—	17.2	6.3
Malta	8.2	11.8	12.8	6.0
Finland	9.0	8.8	16.0	6.0
West Germany	8.5	8.0	14.2	5.6
Netherlands	9.7	10.9	14.6	5.5
Sweden	13.5	9.2	14.3	5.0

SOURCE: United Nations Economic Commission for Europe, Committee on Housing, Building, and Planning, *Exchange of Views on Current Trends and Policies in the Field of Housing, Building and Planning: Statistical Background Paper*, HBP/R.5, July 1973, pp. 5, 7, 8.

NOTE: Japanese statistics group nonresidential construction with machinery and equipment.

dwellings per 1,000 habitants, thus producing 5 to 9 percent of gross national product. The arithmetic mean of this dozen was 6.5 percent. According to UN statistics, only one less developed country reached 5 percent of GNP with housing: Swaziland in 1967 with 5.2 percent. Of 31 developing countries supplying data, 25 reported shares between 1.5 and 3.9 percent.[6] Scope for expansion seems to exist.

One should examine, however, whether the differences between the 7.5 percent of the rule of thumb and the average 6.5 percent of the top builders is one of definition. The standard definition of "Gross Fixed Capital Formation in Residential Buildings," as used in Table 1, is:

> Value of work put in place on the construction of buildings which consist entirely or primarily of dwellings; expenditures on major alterations . . . ; and transfer and similar costs in selling (purchasing). Included are external and internal painting of new buildings and the installation of plumbing, lighting, central heating, air conditioning, fixed stoves and other permanent fixtures that are customarily installed before dwellings are occupied. Excluded is repainting and repair and replacement of worn-out or damaged fixed equipment and fixtures. Classified here as well are the *net* sales proceeds of transaction in existing residential buildings, always leaving out the value of the land, except for new improvements.[7]

For landlords or owner-occupiers, outlays on current repair and maintenance would be counted as intermediate consumption expenditures that form part of actual or imputed gross rent. If tenants pay for the repair, the expenditure is part of their final consumption and added to their rent for national accounting purposes. Also added to space rent are taxes on the property and payments for garbage and sewage disposal, but not water, fuel, or electricity charges. Interest and amortization paid on mortgages would also be part of gross rent. What matters is that interest and monthly payments are actually settled as part of the investment decision and are not a variable part of the flow of consumption expenditures. Dwellings are paid for at the time of sale from the point of view of national accounts, but not from that of the households and financial institutions which have to decide whether or not the price is right.

The employment figure in Table 1 refers to all construction, not just housing, and (excluding Japan) averages 9.8 percent of the labor force. If the housing share in employment is the same 43 percent as its value share in construction fixed capital formation, then 4.2 percent of all workers would be employed at housing construction sites. If the empirical regularity holds of two man-years to produce materials for every three on the site, then the top building nations (excluding Japan) would generate about 7.1 percent of their employment with housing. Average labor productivity in housing would appear to have been about the national average in the period 1968–1971.

Financial Policy

But even the most advanced econometric models that concentrate on explaining the volume of current construction are inadequate for housing policy, which cannot be thought of as fostering an annual crop like apples or carrots. Housing is not just consumed but accumulated, and in a way that differs from stamp collecting. The stock must be continuously renewed and reallocated. As new households appear and break up, as family incomes rise and fall, as the dwellings deteriorate, as streets or businesses are located here or there, families will see the advantages of moving. An appropriate policy toward current production, whether technological or financial, must be an appropriate policy for the stock as well, affecting the relative prices of different housing types and determining what should be built and where. Unfortunately, housing stock redistribution theories are in their infancy.

Purely financial aspects have been studied more thoroughly than stock redistribution since virtually no society is prepared to let funds seep to housing in unaided competition with other investment demands. A poor dwelling is not just an inconvenience for its occupants; it can be the cause of aesthetic, sanitary, social, psychological, and political evils for society. Most countries aim at a financial policy that lets new housing cost more than its occupants can really afford, making up the gap by inducing someone else to save more than they otherwise would.

The inducement not to consume could be compulsory collection by the state in the form of taxes to finance a government construction program for dwellings. Presumably, the government would try to base all decisions, not on market values, but on what would do the most good and least harm to the community. For such aims, much more information is needed than for market solvency, yet government operation of housing tends to lower the supply of information about what different people really want — the price and budget information that a market system generates naturally. For example, it becomes difficult to select which families should vacate dwellings that have become too large for them and that offer a better location for other families. All decisions become personal and therefore bitter, with disagreements, delays, and waste as a result. Government housing authorities even have the tendency to behave monopolistically to maintain and improve the yield of past investment by inhibiting investment in new dwellings and delaying the replacement of inadequate ones.

Because of these dilemmas, housing is not only the first major sector in which market economies try controls, but also the first in which controlled economies recall private capital. According to the United Nations, *World Housing Survey:*

> A basic principle being adopted increasingly in Eastern Europe is mobilizing the initiative of those individuals who have the capacity and the desire to contribute their own efforts and resources to the financing of housing. Thus these countries are moving away from a situation where the state had the primary responsibility for financing housing and in which it concentrated on housing for industrial workers and the lowest income groups.[8]

What is needed is the right kind of public guidance, not public operation, nor public neglect. Without deliberate public action, market forces simply will not allow an optimal expression of housing demand because (leaving externalities aside) they will not bring into being all the institutional mechanisms that can make building, owning, and trading of dwellings safe and flexible. Without public legislation, prodding, and guarantees, mortgage lenders everywhere avoid the unfamiliar as unsound. Perhaps they tend to be so cautious because they have to deal with a very incautious group, the developers. These latter plan to be neither long-term investors nor creditors, but entrepreneurs who are paid for changing the use of a site. They pick up the scent of potential users and occupants, detect their economic characteristics, and then lure just the right kind of long-term holder with financial arrangements that make one group happy with its payments and property and the other pleased with its collections and security.

Public action must guide the proliferation of housing financial institutions and specialized enterprises. With a sophisticated system, each saver, occupant, and intermediary can adjust to market conditions according to his or her preference and avoid judging the motives of others in confrontations. A well-engineered system lets transactions materialize in the public interest with documents, obligations, and rewards adapted to the preferences of each. It will determine who has what rights in the changing stock of dwellings in a manner that is sensitive to both individual and social preferences.

An insurance system to protect depositors, a secondary mortgage market for institutional liquidity, all the refinements of a complete system, will not be spelled out here. A major lack invariably is the absence of financial institutions for serving the poorest one-third of households. Part of the problem lies in scarcity of staff for such institutions, suggesting, above all, the need to train middle level housing specialists with short courses.

In general, maldistribution of income can be readily attacked by means of housing with comparatively less danger to the rate of growth than is caused by measures in other sectors. In no other sector can redistribution go as readily with increased savings, specifically those stimulated by an adroit policy for mortgage finance. Moreover, the potentially low import content of dwellings means less threat to the balance of payments in the first round of credit expansion for housing. Telling countries that they should live within their means, even if they have to borrow to do it, makes no sense apart from housing finance.

A housing policy also must be combined with a land policy, and here the need to redistribute wealth can be forestalled by avoiding the undesirable gains from land speculation before they occur. Land should be allocated according to its rising marginal productivity as urbanization proceeds, but this need should not give unearned income to the rich.

By raising all these issues, it may appear that we have wandered away from technological ones that affect construction. If so, good. Only by doing so can one avoid the temptation of trying to solve non-technological problems with technology. Many economic issues are beyond solution with better physical implements. Technologists who know nothing about these problems may produce new designs, materials, components, and equipment that can become a nuisance. Technology can be certified as appropriate only when the non-technological aspects of a problem are well understood.

2

Conventional Technology, Construction Wages, and Employment

Shifts from one technology to another take place in response to (1) changes in demand, (2) new productive knowledge, and (3) changes in relative wages and prices of capital and materials. Changes in demand will be treated partly in chapter 7. New productive knowledge, or possible innovations, will be analyzed and surveyed in later chapters and two long appendices and will therefore make up the bulk of the work. This chapter explores the third topic, what happens when demand and knowledge are given, but wages and materials prices change at different rates. In formal economic language, this chapter is concerned with substitutions along *given* production functions and later chapters with *shifts* of production functions.

Building technology for housing, in practice and as measured, has not been remarkably dynamic. Houses made of *traditional* materials such as adobe, bamboo, wattle-and-daub, natural stone, and oil drums, using indigenous skills and self-help, are mainly built outside the monetary and measured construction sector. *Modernistic* dwellings of aluminum, fiberglass, plastics, lightweight prestressed or posttensioned concrete modules, and so forth, have made little progress in developing countries. Hence, most commercial building remains at a *conventional* intermediate stage, using bricks, blocks, *in situ* poured concrete, and ordinary carpentry. Technological alternatives involve ways of digging, mixing, sawing, transporting, lifting, and plastering that are well known to experienced builders.

The Elements of Substitution

If two inputs are perfect substitutes for one another, one switches entirely from the first to the second when the latter's price falls from more to less. Either one or the other is used but not both, unless the price (for the task sought) is equal. In building, as in most activities, such perfect substitutes are virtually nonexistent.

One cannot make a building with labor alone, nor with materials alone, and least of all with capital alone. Each of these three is itself a complex aggregate, as is any building, and therefore relative price (and wage) changes can occur within the category, causing changes in composition of *all* categories. The process of substitution is very complex. We shall begin this chapter by pointing out some of these complexities.

To go beyond a general sense of complexity, to make reasonable overall predictions, one must make things as simple as possible but, as Albert Einstein said, no simpler than that. Economic analysis often simplifies inputs by reducing them to labor and capital. Materials are removed from the analysis by reducing output to "value added" — to everything except materials. Can we rely exclusively on that approach here? Can we confine the nonlabor input to the extent to which equipment and structures wear out in the course of production, plus interest? The answer is no.

In building, capital equipment and structures generally are of minor importance, although they matter for specific tasks. Except for a central office and a few on site shacks, the conventional industry does not produce buildings with the use of buildings. Tools and equipment in poor countries often are owned and maintained by workers and included in labor costs. Other equipment may be deployed intermittently for use at this or that site and will wear out with no relation to accounting depreciation. Even for the capital-rich United States, single family housing in 1969 was built with a share of equipment in total costs of only 0.9 percent. For most other types of building, the share was between one and 2 percent (see Table 2).

Better Organization

Labor is saved in construction through better organization and mechanization, and through more easily installed materials. Better

Table 2. ***Percentage Distribution of Costs for Various Types of Construction in the United States***

Type of construction	*Equipment*	*Materials*	*Onsite wages*	*Overhead profit*	*Wages/materials plus wages*
Single family housing, 1962	1.0	47.2	22.1	29.7	31.9
Single family housing, 1969	0.9	43.4	20.4	35.3	32.0
Public housing, 1959–1960	2.5	45.0	35.5	17.0	46.2
Public housing, 1968	—	43.4[a]	32.4	24.2	41.9
College housing, 1960–1961	1.6	52.6	29.3	16.5	35.8
Hospitals, 1959–1960	1.2	53.2	28.2	17.4	34.6
Hospitals, 1965–1966	1.3	50.4	29.6	18.7	37.0
Federal office buildings, 1959	1.9	51.4	29.0	17.7	36.0
Federally aided highways, 1964	11.1	50.3	26.0	12.6	34.1

SOURCE: Bureau of Labor Statistics, *Labor and Material Requirements for Construction of Private Single Family Houses*, Bulletin 1755 (Washington, D.C.: 1972), p. 15.
[a] Equipment included with materials.

organization usually raises overhead costs in the contractor's office, where the organizers dwell. What sophisticated organizers are sophisticated about, above all, is estimation and organization of time. A Swedish group has shown how some time must always be allotted to accidents, delays, reorganizations, and other breakdowns. These may be inefficient, but not to expect them is even more inefficient. Within the remaining "operational" time, an allowance must be made for weather conditions, production imbalances, and interruptions for planning and motivating the work, called a "site time allowance." What remains is "method time," and all of that is not purely productive, laying one brick on another and plastering the bricks. Experienced planning leaves room for a "method time allowance," for moving about the site, waiting for supplies, preventive maintenance, and rest periods.[2] If the need and inevitability of these time allowances is not recognized, the work cannot be organized to reduce their length. When the employer deals with a labor subcontractor (*maestro de obra* in Latin America), he may not know or care how many workers are on the site, much less what they do, except during productive method time. When the subcontractor's demands become "exorbitant," the builder begins to take a more detailed interest. In that case, rising wages displace workers without much other substitution.

This discussion shades over into one of organizational innovations in sitework procedures, discussed in a later chapter, and into one of entrepreneurial capacity and larger issues of planning. A German demonstration project showed that dwelling costs fell by 17 to 21 percent when the sequence of building streets, sewers, and houses was organized logically by well-timed stages.[3]

Good timing also means anticipating other problems in advance, such as shortages of skilled workers. If these can be trained on a continuing basis, sudden shortages will not lead to a cycle of premature mechanization, higher institutionalized wages, and difficulties in recovering labor intensity.

Learning to be a builder means learning from experience what cannot be easily recorded and transferred. What training is possible, however, deserves high priority. The Intermediate Technology Development Group of Britain began its search for an intermediate technology with building. It quickly learned that what was needed most were not physical inventions but better management and business methods. Six four-day conventions of contractors and government technical officers were held at Kaduna Polytechnic in Nigeria, in early 1970. For later work in Kenya a teaching kit for elementary management was developed on the grounds that "the main information barrier in the African situation is not so much between teachers and taught as between those who devise educational material and the teachers."[4] The hardware and materials, as well as the designs, could be left to contractors once they understood how to make decisions about ordering materials, scheduling work, keeping accounts, and the like. Productivity was not so much a matter of better physical means or capital-labor ratios, but of more skilled organization. One had to teach these skills to men with little or no formal education.

Better Materials

After improved organization, more conveniently installed materials are the most common way of saving labor. Such materials usually cost more per square meter and raise inventory costs. Indeed, in construction, materials inventories and work-in-progress are the principal investments by the building firm. One analyst of the sector, Peter

J. Cassimatis, has asserted that fixed capital is therefore not useful in substitution analysis: "The nature of the construction process and prevailing practices in the industry strongly suggest that the financial capital tied up in construction during the construction process . . . should be included . . . . The most appropriate estimate of the industry's capital should be made on the basis of total capital assets (financial and intangible)."[5]

Since data on financial capital, including short-term debts and unpaid bills, are likely to be unavailable or unreliable, one might as well choose materials as the other input besides labor for the simplest types of analysis. Materials data are available and make sense. From the builder's point of view, materials and labor are the variable costs that must be adjusted in accordance with relative price changes to maximize profits. His other costs are fixed overhead or fees that are less subject to market variations and substitution.

The switch from labor to materials is especially harmful to employment when the materials are imported. No primitive support for autarchy is implied here, but due to their bulkiness and low value per ton, conventional construction materials can be produced within each country. In Mexico around 1970 the share of construction wages in dwellings worth US$2,500–$10,000 (without the site) averaged about 27 percent, and the wages share in materials only about 22 percent. The lower share of the latter item is due to the higher degree of mechanization and capital intensity in materials, not to a high import content. In fact, the direct import content of Mexican conventional house-building materials and equipment was negligible by 1965. For other types of construction, the import share was 5.5 percent for materials and 11 percent for equipment. In all types the indirect import requirements were higher, especially if capacity has to be expanded with imported equipment.[6]

Elsewhere, rising wages and standards have caused a switch to imported materials and fixtures, and the employment loss has been much greater. For example, some Asian countries import materials worth 30 percent of construction costs, and many African countries import 50–60 percent of their building materials — metal products, sheet glass, sanitary and electrical equipment, paints, hardware, and even timber.[7]

The effects of relative wage and material price changes have an interesting asymmetry. A rise in wages will lead to a lower use of labor, but so does a relative rise in materials prices, at least in some cases. This paradoxical effect is due to the tendency of contractors and architects to switch to a novel labor-saving material, often imported, if a conventional local material becomes scarce. This odd effect will explain some of the observed negative elasticities.

An observer of Colombian building, James Spillane, has reported that contractors find that "the major problem area in construction is the building materials industry." Any major expansion leads to bottlenecks in bricks, metals, cement, glass, glazed tiles, and sanitary fixtures. Materials may rise in price and yet be purchased months in advance, but the vulnerability of all building booms keeps such excess demand from being a quick incentive for investing in quarries and materials factories.[8] When the investment decision is finally made, the temptation is to set up something foreign, automatic, and labor saving, both in the mill and on the site. Haste and distorted prices during the boom confuse tidy cost comparisons.

Mechanization

In addition to the importation of more easily handled, possibly more prefabricated, materials and components, employment is reduced through mechanization. If you know how much labor time a piece of equipment will save at various volumes, you know what wage level and capital cost bring about the right conditions for substitution. The Productivity Institute of the Israeli Ministry of Housing found that, in the construction of conventional apartment buildings, cranes compared with hoists save 40 minutes of unskilled labor per square meter of floor space. Machinery for cutting and bending steel rods saves 7.2 minutes per square meter. Mechanical delivery systems instead of wheelbarrows save 14.4 minutes per square meter. Buying ready-mixed concrete rather than mechanically mixing it on the site saves 2.4 minutes. Plastering mechanically instead of manually saves 40 minutes per square meter, mainly through less preparation and handling time.[9]

Another Israeli study found that mechanical plastering equipment could save one-fourth of the labor in plastering and reach a breakeven point at 30,000 square meters per year.[10] Such opportunities and calculations underlie the average observed elasticity of substitution in Israel of 1.18, reported in Appendix B, and the 4.8 percent annual rise in construction value added during the 1960s in the face of an average 0.2 percent decline in construction employment. With its per capita product level approaching $2,000, Israel was moving into advanced country status, so that kind of labor saving had become appropriate.

The three processes in which Gerard Boon found the most substitutability in Mexican dwelling construction were excavation, concrete mixing, and materials handling. Foundations could be dug with shovels or mobile cranes. Concrete could be mixed with shovels or a portable cement mixer, or come ready-mixed from the factory. Materials could be lifted with a manual winch, a power winch, or a tower crane. For very large projects, cement could be pumped up through a tube.

Boon compared the costs of these alternatives at typical volumes using the 1965 minimum wage of US$0.28 an hour for unskilled labor and lower accounting wages of US$0.08 and US$0.06. At such wages Mexico would presumably have full-employment equilibrium. Excavation was cheaper with shovels only if the lowest accounting wage was used. In concrete mixing, the intermediate portable cement mixer was cheaper with market prices, and shovel mixing was cheaper with accounting shadow prices and wages. In vertical transport, a tower crane was cheapest for bricks with market prices; a power winch was cheapest for steel and concrete at market prices (unless a pump installation was justified by volume); and a manual winch was best for cement and bricks if accounting prices were used. Boon also found that the elasticity of substitution for each of these processes was close to unity.[11]

Process	*Elasticity of substitution*
Excavation	1.09
Concrete mixing	1.03
Vertical transport	
Manual/power winch	1.20
Power winch/crane	1.15
Manual winch/crane	.97

Rising Construction Wages

Conventional dwellings were built in the 1960s with labor that earned around US$0.25 per hour in some poor countries and over US$4.00 per hour in the United States. These differences were not, however, as great as those in gross domestic product per capita (see Table 3). As a rough order of magnitude, one can say that, according to the cross-sectional evidence, when GDP per capita rises by 200 percent, average construction wages will rise by only 150 percent. Note in Table 3 that construction wages are rising especially fast in middle income countries ($500–$2,000 per capita product). Wages of middle level countries are a multiple of those in poor countries.[12]

A Latin American Cost Comparison

As a result of this rise in wages, can the technique of building be changed to economize on labor? That some kind of economizing is possible is indicated in Table 4, which shows relative costs for an almost identical three-bedroom house in different Latin American countries. The house is a 68.25 square meter, concrete block and stucco dwelling with adequate utilities and services on a 240 square meter lot. In Bolivia

Table 3. ***Per Capita Product and Construction Wages in Selected Countries, 1960–1970, in 1970 U.S. Dollars***

Country	*GDP per capita, last year of series*	*Average hourly wages in construction, 1960–1970*	*Average annual growth rate of construction wages, in percentage*[a]
Less developed			
Kenya	140	.31	
Egypt	217	.14	
Korea	256	—	
Syria	273	.28	3.7
El Salvador	311	.32	
Philippines	344	—	
Turkey	363	.30	
Peru	374	.26	
(Average)	(285)	(.26)	
Intermediate			
Cyprus	824	.43	
Spain	964	.34	
Argentina	968	.51	5.4
Puerto Rico	1,411	1.42	
Israel	1,836	.80	
(Average)	(1,201)	(.69)	
Advanced			
Austria	1,946	.52	
United Kingdon	2,128	1.26	
Belgium	2,633	1.00	
France	2,901	.88	3.0
Sweden	4,055	2.80	
United States	4,734	4.40	
(Average)	(2,983)	(1.81)	

Source: See Appendix B.
[a] Least-squares logarithmic fit.

such a house (without raw land, contractor's overhead, or profit) would cost 42 percent less to build than in Panama. Since per capita product and presumably wages in Bolivia are 71 percent less, one may suspect that in this example, and others, building costs and wages move together but not in proportion.

Suppose that, in rough accordance with Tables 3 and 4, the direct construction cost (column 5) of the house rises from $4,000 to $5,500 as wages rise from an hourly 20 cents to 50 cents. Suppose also that initially the share of labor in costs was 25 percent or $1,000 (5,000 man-hours or 2.5 man-years). If no substitution had been possible, in the better-off country the man-hours would now cost $2,500 at 50 cents per hour, and the share of labor would have risen to 45 percent of costs, an empirically unreasonably high portion. On the other hand, if one assumes that the share of labor has remained a constant 25 percent, then $1,375 would go to labor, meaning only 1.4 man-years or 2,750 man-hours at 50 cents each. The fall in man-hours would be 45 percent. At constant prices, other inputs would have risen by 37.5 percent, and the ratio of other factors to labor would have risen by 150 percent. The elasticity of substitution would have been exactly unity: Each percentage *rise* in the wage-nonwage price ratio means an identical percentage *fall* in the labor-nonlabor employment ratio. If the elasticity were above unity, the fall in employment and the share of labor would be even greater.

Substitution is obviously possible and taking place, and its elasticity is of great importance for employment forecasting and should be measured. The Latin American survey on which Table 4 is based unfortunately did not make direct man-hour estimates, and so we must turn to other sources that lack the advantage of comparing identical dwellings.

Excluded Categories

For the final occupant two expenses, cost of mortgage finance and raw land (its location value), may match or exceed construction costs. Moreover, these two factors may be more amenable to cost-reducing public policies than is construction technology. Nevertheless, land and finance are outside the scope of this study.[13]

Sometimes included and sometimes excluded, depending on the source, is the cost of developing the land, of installing streets, sewers, water, electricity, and possibly gas. A typical level for such costs is 5 percent of total costs, but this amount will vary with the density of

Table 4. ***Cost Breakdown for a 68.25-Square-Meter Concrete Block and Stucco Dwelling on a 240-Square-Meter Lot in Various Latin American Countries and Cities, 1967–1968, in 1970 U.S. Dollars***

Country	*(1)* GDP per capita	*(2)* Onsite dwelling construction cost per square meter	*(3)* Site urbanization cost per square meter	*(4)* Designing fees and overhead	*(5)* Total direct construction cost
Venezuela					
Caracas	$1,791	$65.4	$5.6	$ 601	$6,415
Other	1,091	57.5	4.5	570	5,541
Argentina					
Buenos Aires		78.9	4.5	806	7,272
Other	953	70.2	4.5	637	6,511
Uruguay	754	59.2	3.4	500	5,350
Panama	693	67.6	5.1	602	6,434
Chile					
Santiago	929	66.5	5.5	1,041	6,886
Other	676	56.4	4.0	648	5,441
Jamaica	636	60.9	5.2	672	6,064
Mexico					
Tijuana		56.4	3.6	387	5,099
Interior	621	48.5	2.8	327	4,311
Costa Rica	509	38.3	4.0	443	4,005
Nicaragua	452.5	60.9	3.5	784	5,788
Colombia	371	38.5	3.7	435	3,931
Peru	371	44.0	4.7	514	4,639
Guatemala	359.5	51.3	5.9	876	5,796
Brazil					
Rio de Janeiro and São Paulo	1,012	70.2	5.4	628	6,718
Other	331	51.6	5.4	653.5	5,474
Dominican Republic	326	71.0	3.5	771	6,470
El Salvador	317	62.0	5.1	620	6,068
Honduras	292	38.3	3.4	354	3,781
Ecuador	268	45.1	4.7	436	4,649
Paraguay	259	51.3	2.5	423	4,517
Bolivia	197	34.3	3.4	562	3,720
Unweighted average	$ 600.4	$56.0	$4.3	$ 595	$5,453

settlement, hence with both the cost of raw land and the number of stories. In Table 4 reported site costs averaged US$3.50 plus $4.30 per square meter for urbanization. These expenditures bring the share of the site in total costs to 25 percent. This share roughly equals offsite expenditures, leaving about half for onsite labor and materials. In the large cities listed in Table 4, all these expenditures are about double those in the poorest countries. Increasing the number of stories lowers the share of both labor and land in total costs and simultaneously leads

Table 4. — continued

(6) Sales and legal insurance expenses, and so forth	(7) Profit and risk at 10 percent	(8) Offsite cost, sum of columns 4, 6, and 7	(9) Share of offsite cost in total cost without land	(10) Undeveloped site cost per square meter	(11) Total cost
$658	$708	$1,967	.25	$13.1	$10,934
478	605	1,653	.25	4.5	7,738
641	791	2,238	.26	4.5	9,790
563.5	709	1,909.5	.24	3.4	8,593
394.5	575	1,469.5	.23	1.1	6,590
560	700	1,862	.24	3.2	8,459
506	739	2,286	.28	4.5	9,213
453	589	1,690	.26	3.4	7,295
547	662	1,881	.26	5.6	8,532
453	556	1,396	.23	3.8	7,008
376	469	1,172	.23	2.7	5,804
306.5	432	1,181.5	.25	1.9	5,206
518	631	1,933	.28	4.7	8,069
353	428	1,216	.26	4.5	5,794
412.5	505	1,431.5	.26	4.5	6,638
458	625.5	1,959.5	.28	3.8	7,780
575	729	1,932	.24	3.5	8,855
418	589	1,659.5	.26	1.9	6,930
575	704	2,050	.26	1.3	8,873
535	660	1,815	.25	4.3	8,300
308	409	1,071	.24	3.6	5,352
375	503	1,314	.24	3.8	6,427
349	487	1,259	.235	2.0	5,827
301	402	1,265	.29	3.4	5,235
$463	$592	$1,635	.25	$ 3.9[a]	$ 7,468

[a] Without Caracas, $3.5.

to a qualitatively different product if there is a shift from single to multifamily housing. The issues involved are discussed in detail in chapter 6.

Much of the analysis of purely structural costs will proceed in terms of wage and materials price indices together with the share of either factor in their combined total. A two-to-one ratio seems to be typical, say, 56 percent for materials and 28 percent for onsite wages. Left over

Table 5. *High and Low Areas in Latin America for Various Components of Construction Costs*

Component	*Three highest*	*Three lowest*	*Ratio of highest to lowest*
Onsite dwelling construction cost per square meter	Buenos Aires Dominican Republic Rio de Janeiro/São Paulo	Colombia Honduras Bolivia	2.3
Site urbanization cost per square meter	Guatemala Caracas Santiago	Honduras/Bolivia Mexico Paraguay	2.4
Designing fees and overhead	Santiago Guatemala Buenos Aires	Tijuana Honduras Mexico	3.2
Total direct costs	Buenos Aires Santiago Rio de Janeiro/São Paulo	Colombia Honduras Bolivia	2.0
Sales, legal, and insurance costs	Caracas Buenos Aires Rio de Janeiro/São Paulo	Honduras Costa Rica Bolivia	2.2
Total offsite costs	Santiago Buenos Aires Dominican Republic	Costa Rica Mexico Honduras	2.1
Land costs	Caracas Jamaica Nicaragua	Costa Rica Brazil (other) Uruguay	11.9[a]
Total costs	Caracas Buenos Aires Santiago	Mexico Bolivia Costa Rica	2.1

[a] Jamaica to Brazil, 2.9.

are 11–21 percent for other expenditures, not including profits, and something needs to be said about them.

What stands out most is the variability of what is put into this third category. Usually it includes the earnings of foremen and technicians who are on the builder's permanent payroll, but who may actually spend most of their time on the construction site. Administrative expenses and offsite wages are invariably included here, as well as equipment, if not listed separately. Designing fees are included unless one has cost estimates for *given* designs. Construction financing, insurance, and legal fees of various types also belong here. For a variety of reasons, taxes, sales expenses, and profits are sometimes included and sometimes not. Taxes may not reflect a net cost to society from the building process and may therefore be omitted. If land and urbanization costs are excluded, then sales costs can be left out as a cost that refers to the whole, not just to the structural part. Profits must be included as an incentive to keep an enterprise committed to building houses, but poor data and the difficulty of distinguishing between the salary, capital cost, and "pure" elements in profit make this an unreliable element. Often an arbitrary 9–11 percent is simply assumed.

To sum up, in most cases, differences in profits, overhead, and other costs reflect alternative definitions more than alternative technology. The category can be neither ignored nor used with analytical rigor.

Another look at Table 3 shows that Latin American offsite costs ranged from 23 to 28 percent of all costs without land (but including urbanization). Since profits were assumed to be 9 percent of the total (including profits themselves, making them 10 percent of other expenses), the offsite share without profits was about 16 percent. As with other expenditures, the large South American metropolitan areas charged about twice as much for these services as did such countries as Honduras and Bolivia (see Table 5).

Differences in Skills and Productivity

A more tempting disaggregation would be that of labor into skilled and unskilled categories. Statistics on the relative use and wages of skilled and unskilled workers are often available, and for many places and industries, studies of the growth of skills and the narrowing skill differential have, in fact, been made. For building, we again have a problem of definition and a disconcerting tendency among some countries to use *three* categories. Experts working for the Economic Commission for Africa found that the skill differential ranges from 6:1 for Ethiopia to only 3:2 for Kenya. They concluded that using a weighted average (one-third skilled, two-thirds unskilled) gave a more reliable wage index (see Table 6). In this study, we shall analyze skill patterns when the data seem reliable, but shall nevertheless more often use aggregate wages and man-hours.

No worker receiving any wage is unskilled in all respects, and very few are "totally" skilled. Since the definitions are arbitrary to begin with, one can hardly expect them to be uniform in different countries. Saying "more" and "less" skilled in the setting of some cultures might be better.

International contractors who work in several countries know that an hour of unskilled or skilled work is not a universal constant, like a liter of water or an electrical kilowatt. Many firms have developed productivity coefficients for making cost estimates. A common practice is to assume that basic labor input stays the same, but that if productivity in an area is only half, then twice as many workers will be needed. This number is then multiplied by the average wage.

Table 7 shows how five European contractors viewed workers abroad in the last decade. Apparently, skilled workers in Hong Kong were rated equal to Europeans, but unskilled workers in some Near Eastern countries were thought only one-fourth as productive. All these ratios must be viewed with skepticism. A rough consensus seems to hold that productivity ranges from one-half to two-thirds in less as compared with more developed countries. An estimator for Firm C

Table 6. ***Relative Wages of Construction Workers in Selected African Countries, 1964***

Country (1)	*Daily wage of skilled workers, U.S. dollars* (2)	*Daily wage of unskilled workers, U.S. dollars* (3)	*Weighted average* $\frac{(2) + 2(3)}{3}$ (4)
Libya	3.64	1.18	2.00
Upper Volta	3.24	.96	1.72
Mauritania	2.64	1.20	1.68
Ghana	1.72	.91	1.18
Egypt	2.01	.72	1.15
Madagascar	1.60	.80	1.07
Ethiopia	2.40	.40	1.07
Kenya	1.00	.67	.78

SOURCE: United Nations Economic Commission for Africa, "Pilot Enquiry into House Building Costs," HOU/WP/5 (Addis Ababa: 1964), p. 36.

Table 7. ***Experience with Labor Productivity and Costs of Five European Overseas Contractors, 1966***

Firm A	*Firm B*	*Firm C*	*Firm D*	*Firm E*
"In Libya we found we needed 50 percent Europeans instead of our usual 4 percent." *Ratio of labor productivity to home country's* South Africa .6 Pakistan .5 Thailand .4 Argentina .7 Venezuela .6 Brazil .4 Australia .6 Great Britain .7 France .7 Norway .9 Sweden 1.0 Denmark 1.0 Germany 1.0 Netherlands 1.1 Canada 1.2 United States 1.3 "Costs abroad always equal our home costs after pluses and minuses are balanced. They are probably within 5 percent, but just to be safe, I'll say within 10 percent."	*Ratio of labor productivity to home country's* Saudi Arabia, Kuwait skilled .5 unskilled .25 Iran, Jordan .67 Lebanon .75 Central Africa carpenters .7 others .5 Hong Kong skilled 1.0 unskilled .5 Malaysia .5 South America steelworkers .33 other skills .67 unskilled .5 "Using labor contractors has advantages in hiring and firing labor and adapting to the labor laws. We phase workers in and estimate the rate of work in accordance with the schedule and then either hire more or fewer."	*Ratio of labor productivity to home country's* For all developing countries: .33 "It gets too complicated to break the job down into masons, steelworkers, etc. . . . In the Sudan and Pakistan, you must have two men on a machine to relieve each other every two hours. Each skilled worker brings two helpers. Labor intensity is not only a problem of meeting a schedule but also a problem of crowding more workers on the site. . . . In Arabia easy-to-assemble steel shuttering has to be specified to overcome lack of experience."	"We specialize in West Africa. A steel portal frame can now be machined in Nigeria. Cement contractors and the West African labor force are now quite skilled. Our byword is still 'avoid the wet trades' concrete and plastering. One has to learn that the Sahara wind dries out wood and therefore avoid wooden doors and frames. Use only metal doors. Higher material costs offset lower labor costs. For housebuilding, cost per square foot is the same (as at home)." "A European can supervise no more than 50 Africans. At least Africans, once trained will do as told. But Chinese at Hong Kong listen, agree, but then do things the way they have always been done. Wherever possible we change to using local techniques.	"The lower cost of labor in overseas countries is compensated by lower output and . . . probably deteriorates from Hong Kong to West Africa. In West Africa the output of a carpenter on shuttering is only about 1 sq. yd. per day . . . the best sort of (human) material does not find its way into the lower ranks of the construction industry (in India and Ceylon)." "As we built our organization (in India), we found supervisors, some of the best in the world." "The cost of construction, though not necessarily the price paid, is roughly the same anywhere in the Commonwealth."

SOURCE: Personal interviews by the author.

said their use of one-third for labor productivity was too low and had recently cost them a contract. "Even with .36 I could have landed the job. . . . Our company really doesn't do much abroad at the present time."

The differences among the five contractors is a reminder that there not only are differences in definitions and labor forces, but also among the entrepreneurs — their perceptions, attitudes, and ways of choosing. We should not pretend that their choice of labor and of wages in total costs is the optimal response to cost signals about a universally homogeneous input. We should not, but we might err in that direction since the alternative is to pretend that obvious patterns have no meaning. At least, contractors *try* to be rational about their employment decisions, as the following excerpts from a "Memorandum for Visiting Sites Prior to Tendering" of Firm A might suggest.[14] It calls for information on the following points:

(1) availability of labor: skilled, semiskilled, unskilled;
(2) languages spoken and races of the different kinds of labor;
(3) whether labor availability is subject to seasonal variation;
(4) legislation governing the employment of labor: native, European, or other nonnative;
(5) existence of trade unions or similar organizations and their importance and influence;
(6) legislation and restrictions regarding importation of skilled and expert workmen;
(7) recruitment of native labor: method and cost of recruiting, length of contract, cash payment or payment in kind (food, clothing, bedding, housing, medical service);
(8) payments in kind to native labor: rations and prices;
(9) ruling or minimum wage rates;
(10) whether minimum rates are fixed by law or regulation, or by negotiations with trade unions;
(11) social legislation or customs concerning accident and illness benefits, unemployment benefits, yearly holidays, and national or religious holidays and payment on such;
(12) standard weekly working hours, how worked, payment for overtime, regulations regarding work on Sunday and holidays;
(13) the observation of religious customs by the whole or sections of the population, such as Ramadan by the Mohammedans (not

allowed to eat between sunrise and sunset during the month of Ramadan, which affects output and tempers); and

(14) estimated output of labor in relation to some known locality.

The Share of Labor and Housing Quality Differences

A preliminary and not very accurate impression of the substitutability of labor for materials in conventional technology may be gained from Table 8. These "typical" proportions suggest that labor costs for the period cited had the largest share in the Middle East and North Africa, followed in order by sub-Saharan Africa, the rest of Asia, and Latin America. Since the average cost per square meter in all Africa and the Middle East was $10 (or 26 percent), higher than in the rest of Asia and Latin America, one might guess that what is really more labor intensive is high cost housing. In light of the Mexican data presented in Appendix A, that guess would be incorrect. Moreover, a wide variety of square meter costs, from below US$30 to over $50, is included for each of the areas listed in Table 8, and the pattern does not seem to be much different for given price ranges. Obviously, Table 8 does not refer to the construction costs of housing for average families, since in most developing countries these can afford only old housing or shacks, not even a modest commercially built structure. For example, the Ethiopian housing was intended for power station technicians, and the Kenyan housing was built for noncommissioned police officers. These and other prospective occupants for low cost housing earn above-average incomes.

A country which stands out in Table 8 as being different in these shares and costs, such as Egypt for the Middle East, also seems to differ in general characteristics from its geographical neighbors. It would be surprising if the ratios of crowded Egypt were closer to those of fairly underpopulated Libya and Kuwait than to those of Hong Kong and Costa Rica. Nevertheless, apart from these few exceptions, one does get an impression of more similarity within than among geographical regions.

This rough regional consistency could be due to general or specific price-wage characteristics. A general characteristic might be that, for example, Latin America is more industrialized, urbanized, and developed than Africa. Another such generality is the greater density of settlement in Asia. Lack of timber in the Middle East is a characteristic specifically related to building. So are the appraisals of relative labor productivity used by the international contractors.

If anything can be deduced from the array of figures in Table 8, it could be that the substitutability of materials for labor is somewhat less than unity. Construction labor might be less productive in some geographical regions than in others because of inexperience, lack of training, inferior organization, cultural patterns, climate, intractable building materials, or a wide variety of other causes that will not be pursued here. If labor reasonably prefers to stay in other economic sectors where its productivity and earnings are higher, construction wages cannot fall to the low level of construction productivity. With low

Table 8. ***Onsite Labor and Materials Costs as a Share of Structural Cost in Selected Countries***

Country	*Onsite labor, in percentage*	*Materials, in percentage*	*Share of onsite labor (sum of labor and materials costs), in percentage*	*Cost per square meter, in U.S. dollars*
Middle East and North Africa				
Lebanon, 1970	52	39	57	35
Saudi Arabia, 1970	43	48	47	48
Libya, 1965	42	52	37.5	41
Morocco, 1965	40	49	45	34
Jordan, 1970	38	56	39	40
Kuwait, 1970	35	56	39	65
Syria, 1970	34	57	38	32
Iraq, 1970	33	58	36	36
Egypt, 1964	25	60	29	27
Unweighted average	38	53	41	43
Other Africa				
Ghana, 1964	39	47	45	44
Sudan, 1965	30	46.5	39	49
Senegal, 1964	28	54	34	36
Madagascar, 1964	25	66	27	33
Kenya, 1964	25	70	26	45
Ethiopia, 1964	20	63	24	53
Unweighted average	28	58	32.5	43
Other Asia				
Afghanistan, 1970	30	59.5	33	13
Sri Lanka, 1970	28	56	33	42
Philippines, 1970	27	63.5	30	51
E. Pakistan, 1960	27	53	34	29
Hong Kong, 1970	27	56	30	29
W. Pakistan, 1960	27	53	33	21
Republic of Korea, 1970	25.5	63	29	53
India, 1970	23.5	66	26	28
Unweighted average	27	59	31	33

Table 8. — *continued*

Country	*Onsite labor, in percentage*	*Materials, in percentage*	*Share of onsite labor (sum of labor and materials costs), in percentage*	*Cost per square meter, in U.S. dollars*
Latin America				
Colombia, 1971	27.5	—	—	52.5
Mexico, 1970	27	58.5	35	42
Costa Rica, 1968	25	58	30	25
Guatemala, 1968	19	46	30	24
El Salvador, 1965	17	59	22	33
Honduras, 1963	16	60.5	21	34
Unweighted average	22	56	28	35
United States				
Public housing, 1959–1960	36	45	46	115
Single family housing, 1969	20	43	32	169

SOURCE: United Nations Economic and Social Council, *World Housing Survey*, E/C.6/129 (New York: September 1973), pp. 221–24. The figures are not national averages but breakdowns of presumably typical patterns. I have added the Mexican row as an average of low cost single and multifamily dwellings. United Nations Economic Commission for Africa, "Pilot Enquiry into House Building Costs," HOU/WP/5 (Addis Ababa: 1964), p. 30.

productivity and relatively high wages, the only way to keep the share of labor in costs from rising is to substitute more expensive, more easily worked materials for labor. Since the low labor productivity regions, Africa and the Middle East, have the higher shares of labor in total costs, one may presume that the substitution elasticity is below unity. High elasticity would make the share fall as unit costs rise.

Note that the labor share in single family housing labor-and-materials costs is 32 percent in the United States. Such housing is largely built with nonunion labor. In public housing, largely built with union labor at substantially higher wage rates, the share of labor rises to 46 percent. Even though the share of equipment also rises from about one to 2.5 percent, the elasticity of substitution does not seem very high. But here we are definitely dealing with noncomparable types of housing: middle income, single family housing as opposed to low income, multifamily, multistory apartments that cost one-third less per square meter. Changes in the share of labor in response to varying wage rates should be observed for houses of *given* size and quality.

The way to study the relation between labor shares in output and wage rates is with production functions, and these will be introduced at the end of this chapter. Unfortunately, production functions are gluttons for data and can do little with a gourmet morsel. Perhaps garbage-in/garbage-out is better than morsel-in/nothing-out from a computer, but why should one lose the morsels altogether? On these matters, perhaps the most savory statistical morsel comes from Mexico, and it can be found in Appendix A. Some of its details will be used below, in a comparison of Mexico with Colombia and the United States.

In drawing this comparison, good housing for the solid middle class is all that Table 9 can cover since low cost, minimal, and luxury housing data are not available for Colombia. A detailed Brazilian study has confirmed the Mexican pattern shown in Table 10 and Appendix A.[15]

Number of Stories and Quality

Most striking in Table 9 is that, for a given quality, higher dwellings cost more per square meter but have a smaller share of onsite wages in structural cost; the pattern is virtually identical for Mexico and Colombia. Since the Colombian wage rates used were 24 percent above the Mexican, the constant share of labor would seem to imply a unitary elasticity of substitution between labor and materials.

But when these Latin American shares are compared with those of labor in the United States at wage rates that are five to eight times higher, one finds that shares are negatively associated with wages for single family housing and positively with high-rise housing. The plausible conclusion is that conventional technological options and substitution possibilities are greater for single family housing than for multistory apartments. Multistory buildings might have a lower labor content to begin with, but as wages rise, further substitution will lag until the wages share actually begins to exceed that of single family housing. At some point, with sufficient volume and density restrictions, a dramatic shift to industrialized systems building (ISB) becomes profitable. This option, which will be discussed in chapter 6, was not being used in U.S. public housing in 1959–1960, the period covered in Table 9.

Some Mexican Housing Cross-Section Particulars

Table 10 shows, for Mexico, what happens to the share of labor when everything is held constant except quality and number of stories (based on more detailed tables in Appendix A). The construction labor

Table 9. ***Hourly Earnings, Share of Labor, and Comparative Building Costs in Mexico, Colombia, and the United States***

Type of housing	*Daily earnings per worker, current U.S. dollars*	*Share of onsite wages in structural cost including overhead, in percentage*	*Cost in U.S. dollars*	*Number of square meters*	*Cost per square meter, in U.S. dollars*
Single family houses					
Mexico, "good," 1970	3.82	28	8,924	164	54
Colombia, 1971	4.56	29	6,600	90	73
U.S. average, 1962	24.56	22	17,867	115	155
U.S. average, 1969	31.52	20	25,856	151	171
Multifamily 4–5 story buildings					
Mexico, "good," 1970	3.82	27	5,018	90	56
Colombia, 1971	4.72	26	7,534	90	84
High-rise buildings					
Mexico, "good," 1970	3.82	24	6,368	90	71
Colombia, 1971	4.97	24	9,528	90	106
U.S. public housing 1959–1960	25.12	36	10,598	92	115

SOURCES: For Mexico, Christian Araud et al., *Studies on Employment in the Mexican Housing Industry*, Development Center Studies, Employment Series No. 10 (Paris: OECD, 1973). For Colombia, Departamento Nacional de Planeación, *Posibilidades de Reducción de Costos en Edificación* (Bogotá: November, 1972), and see Appendix C. For the United States, Bureau of Labor Statistics, *Labor and Material Requirements for Construction of Private Single-family Houses*, Bulletin 1755 (Washington, D.C. 1972), p. 15.

Table 10. ***Labor Earnings, Materials, and Overhead as Shares of Structural Cost for Different Types of Mexican Housing, 1970, in Percentages***

Shares and other characteristics	*Minimal single family house*	*Low cost single family house*	*Low cost apartment*	*Good single family house*	*Good low-rise apartment*	*Good high-rise apartment*	*Luxury single family house*	*Luxury high-rise apartment*
Labor earnings (construction and materials) :: structural cost	44	43	45	42	42	39	38	35
Construction earnings :: structural cost	32	31	32	28	27	24	22	18
Materials (indirect labor) :: structural cost	57 (12)	60 (13)	57 (13)	61.5 (14)	63 (15)	66 (15)	67 (15.5)	75 (17)
Overhead without profit :: structural cost	11	9	11	10.5	10	10	11	7
Onsite wages :: onsite wages plus materials	36	34	37	32	30	27	26	23
Structural cost without land, U.S. dollars	1,035	2,576	2,875	8,924	5,018	6,368	28,830	9,161
Dwelling area, square meters	47	64	67	164	90	90	384	112
Cost per square meter, U.S. dollars	22	40	43	54	56	71	75	82

SOURCE: See Appendix A.

content falls from 32 to 18 percent of the structural cost of the dwelling (that is, cost omitting profits, land, urbanization, and sales expenses). By the same token, the share of materials rises from 57 to 75 percent. Materials in the best dwellings have a slightly higher labor content than those in the cheapest houses, 23 compared with 21 percent. But since this percentage refers to a larger total, the labor-in-materials share actually rises from 12 to 17 percent of structural costs, offsetting in part the lower labor intensity of good and luxury housing.

Instead of falling from 32 to 18 percent from minimal houses to high-rise luxury apartments, the labor share falls only from 44 to 35 percent. Low cost single family houses have a labor share, direct and indirect, only 13 percent greater than that of luxury houses. The real employment generating effect of funds for low cost housing is that less money is diverted to land purchases, and it does not simply replace other funds that would, in any case, have been spent on housing. This land-financial effect can double or triple employment generated by a housing project (see Appendix A, Tables A1 and A2, and related discussion).

Real and Apparent Changes in the United States

The way time mingles changes in quality and in relative prices may be illustrated with U.S. data for 1962 and 1969. During this period construction wages rose by 28.3 percent and other construction input prices by only 21.5 percent. The share of onsite labor earnings in structural costs of single family housing fell from 22 to 20 percent. Nevertheless, one cannot estimate elasticities of substitution from this information with confidence because of changes in quality and demand.

For the average single family house, area increased by 30.8 percent and construction cost in real terms by 44.7 percent (see Table 11). Construction cost per square meter rose by 10.6 percent in real terms. But all these increases would have been less if the type of house had been held constant.

A three-bedroom house is a more standardized commodity than the "average" house. Its total construction cost during 1962 – 1969 rose by only 29.5 percent in real terms and by 6.4 percent per square meter. But even these houses improved in terms of space, rising from 107.2 to 130.5 square meters (21.7 percent larger). The number of square meters built per onsite man-hour rose from only 10.55 to 10.68 (1.2

Table 11. ***Comparative Data for U.S. Single Family Housing, 1962–1969***

Three-bedroom houses	*1962*	*1969*	*Percentage change*	*Percentage deflated by construction price index*
1. Square meters per house	107.2	130.5	21.7	—
2. Construction cost per house, current dollars	$13,917	$22,083	58.7	29.5
3. Gross construction output per onsite man-hour, current dollars	$13.70	$18.18	32.7	8.3
4. Square meters per 100 onsite man-hours	10.55	10.68	1.2	—
5. Construction cost per square meter, current dollars	$129.82	$169.21	30.3	6.4
6. Average hourly earnings, current dollars	$3.07	$3.94	28.3	—
7. Single family construction price index	100.0	122.5	22.5	—
All single family houses				
8. Square meters per house	115.2	150.7	30.8	—
9. Construction cost per house, current dollars	$14,585	$25,856	77.3	44.7
10. Gross construction output per onsite man-hour, current dollars	$13.89	$19.23	38.4	13.0
11. Square meters per 100 onsite man-hours	10.93	11.30	3.4	—
12. Construction cost per square meter, current dollars	$126.6	$171.6	35.5	10.6
13. Man-hours per house (direct and indirect)	2951	3520	19.3	—
14. Man-years at 1,800 hours	1.64	1.96	18.9	—
Percentage distribution of man-hours				
15. Construction	41.6	45.3		
16. Onsite	35.6	38.3		
17. Offsite	5.9	7.3		

Table 11. — *continued*

Percentage distribution of man-hours	*1962*	*1969*	*Percentage change*	*Percentage deflated by construction price index*
18. Indirect	58.4	54.7		
19. Building materials, manufacturing	30.2	29.9		
20. Wholesale trade, transportation, and other services	15.3	14.6		
21. Mining and manufacturing other than final stage building materials	12.9	10.2		

SOURCE: Bureau of Labor Statistics, *Labor and Material Requirements for Construction of Private Single-family Houses,* Bulletin 1755 (Washington, D.C.: 1972), pp.11 – 15.

percent). Economies of scale associated with area probably offset improvements in quality.

If we did not know about these qualitative changes, we would be most puzzled by the changed distribution of man-hours (Table 11, lines 13 – 16). Although construction wages rose faster than other wages and other costs, the number of man-hours increased as a share of the total!

Compared with the Mexican distribution of man-hours (Appendix A, Tables A1 and A2, lines 5 and 10), the U.S. man-hour distribution makes sense. U.S. construction man-hours are about 44 percent of all direct and indirect man-hours, compared with about 63 percent for Mexican good and luxury housing. With development the percentage share of man-hours declines by about one-third, but because of relatively rising wages, the earnings share declines only by one-sixth, from 25 to 21 percent. Expressed differently, the U.S. worker, directly and indirectly, produces about twice as many square meters of housing, six times as much value, and is paid over eight times as much as the Mexican. Economic development means quantity, quality, and income redistribution.

It may be that crude comparisons of substantially different housing in sharply different countries show some basic patterns. When all types of housing are combined and other types of construction are considered as well, the resulting mixture calls for several grains of salt. Since salt is not too costly, we shall proceed.

Trends and Production Functions

Falling Mexican Wage Shares

Figures are available from Mexico. As Table 12 shows for the years 1950–1967, wages rose at an annual rate of 8.1 percent; construction materials prices at 6 percent; and the gross construction price index rose at 6.8 percent. The share of wages in value added, in gross construction, and in the sum of wages and materials fell. The elasticity of substitution was clearly above unity, unless the changes in composi-

Table 12. *Trends in Mexican Construction: Selected Years and Least-Squares Logarithmic Growth Rates* '

	1950	*1956*	*1962*	*1967*	*Growth rate, 1950–1967*
	Price Indices 1960 = 100				
1. Gross construction prices	36.8	73.0	98.6	127.3	6.8
2. Materials prices	38.9	78.2	104.1	115.4	6.0
3. Wages	34.0	65.8	90.7	144.1	8.1
4. General price index	50.8	83.0	106.6	123.9	5.0
	Millions of 1960 pesos				
5. Gross construction	6,840	10,640	14,710	24,950	7.0
6. Construction, value added	3,000	4,660	6,440	10,930	7.0
7. Capital stock	1,550	2,460	3,680	5,070	6.9
8. Fixed capital	870	1,420	2,210	2,610	6.9
9. Depreciation	21	33	56	65	7.1
10. Wage bill	2,400	3,150	4,160	5,240	4.6
11. Surplus, 6 – (9 + 10)	580	1,470	2,230	5,620	11.7
	Ratios (1960 prices)				
Wage bill : Value added	.80	.68	.64	.48	
Wage bill : Wages materials	.38	.35	.33	.27	
Fixed capital : Wage bill	.36	.45	.53	.50	
Depreciation + surplus: total capital	.39	.61	.62	1.12	
Current wage bill : Gross construction, current prices	.32	.27	.26	.24	
Current wage bill : Value added, current prices	.71	.61	.59	.54	

SOURCE: Banco de Mexico, S.A., *Cuentas Nacionales y Acervos de Capital, 1950–1967,* (Mexico City: 1969). Later years omit the key figures for the wage bill.

tion, as described above, account for the pattern. In real terms, the wage bill rose only at an annual 4.6 percent, compared with a 7 percent growth rate of construction output.

The way to support such assertions is to run logarithmic regressions that can be derived from CES (constant elasticity of substitution) production functions.[16] The Mexican results using this method are shown in Table 13. The range is from a solid elasticity of 1.4 between materials and labor; to a weaker one of .9 with capital; and finally, using value added, to two which are feeble, even negative. A problem with Mexican data is the lack of employment statistics and the consequent need to use the wage bill deflated by the wage index as a measure of labor inputs. Value added is not a perfect tool for gauging what happens in construction since the principal substitution is that between onsite labor and the materials that are omitted from value added.

Good figures for capital costs were not available, so value added less the wage bill, plus depreciation, has been used as the cost of capital. The elasticity was .88, but the R^2 was only .203. If depreciation is omitted as a possible fiction, the elasticity rises to .92, but the R^2 falls to

Table 13. ***Elasticities of Substitution in Mexican Construction, 1950–1967***

(1) Dependent variable	(2) Independent variable	(3) Intercept	(4) Slope coefficient (standard error)	(5) R^2	(6) Elasticity of substitution
1. $\ell n \frac{\omega}{P}$	$\ell n \frac{M}{W_r}$	−.578	.726 (.131)	.658	1.38
2. $\ell n \frac{\omega}{K}$	$\ell n \frac{K}{W_r}$	5.016	1.140	.203	.88
3. $\ell n \frac{V}{W_r}$	$\ell n\ \omega$	−.754	.276 (.054)	.621	.28
4. $\ell n\ V$	$\ell n\ W_r$, $\ell n K$, $[\ell n\ W_r - \ell n K]^2$	−.548	1.386 (1.058), −.244 (1,237), 1.555 (1.860)	.954	−6.76

SOURCE: Banco de Mexico, S.A., *Cuentas Nacionales y Acervos de Capital, 1950–1967* (Mexico City: 1969). Later years omit the key figures for the wage bill.

NOTE: W = wage index; P = materials prices index; M = construction materials in real terms; W_r = real wage bill; K = construction value added less the wage bill, plus depreciation.

.181. Note that the largest share of capital was in the form of stocks, not equipment (Table 12, lines 7 and 8). It is reassuring that the regression using the most reasonable variables also yields a credible elasticity: 1.4.

For the United States, Peter Cassimatis estimated an elasticity of 1.12, regressing value added per man-hour against wages per man-hour, plus a time trend. The U.S. share of construction employee compensation in total output fell from 37.7 percent in 1947 to 28.1 percent in 1965. A similar 1965 regression for 16 countries by Gerard Boon arrived at an elasticity of .97. None of these make any allowance for the indirect labor in materials and building equipment.

Multicountry Comparison

To check this apparent value of a substitution elasticity around unity, data were examined for a large number of countries; 19 were selected as having enough data for running time series regressions during the 1960s. The pitfalls that bedevil this type of effort are well known and too dreary to be repeated. Most of the findings are given in Appendix B. A cross-section of all 19 could not be examined since wage data were inadequate for Korea and the Philippines and since only an employment index (without a base) was available for Egypt and Peru. As equations (7) and (8) show, the elasticity of substitution was 0.8 if the dependent variable is value added per worker (*V/L*) and 0.9 if it is output per worker (*O/L*), partly reflecting materials-labor substitution.

$$\log \frac{\hat{V}}{L} = \underset{(.116)}{3.54} + \underset{(.281)}{0.79} \log \omega \qquad R^2 = .377. \tag{7}$$

$$\log \frac{\hat{O}}{L} = \underset{(.128)}{3.83} + \underset{(.309)}{0.86} \log \omega \qquad R^2 = .375. \tag{8}$$

The most obvious impression from Appendix B is that elasticities vary widely from one country to another and, for a given country, from one estimating procedure to another. Irresistibly, one takes another look at the data to see if findings for this or that country should not be rejected. For example, using value added per worker and wages for the United States in the 1960s yields a negative elasticity of −.38, quite different from Cassimatis's 1.12. But the Vietnam War and associated financial crises affected construction in a way that made the second half of the decade incomparable with the first. And Cassimatis limited his observations to "full-capacity" years.

The temptation is to scrutinize every eccentric number until one has a pretext for throwing it out. Less recalcitrant numbers are like diplomatic travellers; the obedient ones do not have to open their luggage. Such cleansing procedures have a remarkably salubrious effect on the plausibility of estimates.

For example, if only seven high growth countries with a flourishing construction sector (Kenya, Korea, Cyprus, Spain, Puerto Rico, France, and Austria) are counted, one finds a decent average elasticity of 0.9 with value added per worker and of 1.05 with output per worker. For five European countries that probably generated good data, regardless of growth, the two elasticities are 1.01 and 1.32. To repeat, one does expect a little more substitutability with output instead of value added since that brings in the role of materials. But a specification using output, employment, and materials data (not prices or wages) gives an elasticity of only .88 for these European countries and of .74 for the high growth countries (provided a time variable is added). Other combinations of countries and specifications give more awkward results.

So do the best equations tell us something about the level of the "true" elasticity? Or does anything in the cozy .70 – 1.30 range show us what raw data are not too unsavory, when a short period is not too brief to be serviceable, and which specifications make sense? Are we learning something about builders' options in the real world, or only about the hazards of data collection and theorizing? If we already know what works in practice and what trends are plausible, why fabricate abstract models that can either add nothing or be misleading? Since this study is not about epistemology, we do not have to answer those questions; in fact, we did not even have to raise them. Moreover, in the Stone Age, when caves made dwelling construction a needless industry, people presumably did not worry about substitution at all. Nevertheless, we shall push on to a conclusion.

Conclusion: Harnessing Elasticity

Substitution of other inputs for labor in building can and does take place. The elasticity of substitution with capital and better materials is not invariably unity so that the share of wages in costs will not unshakably be one-quarter, one-third, or whatever. The share will also vary with the size and quality of dwellings and with the number of dwellings per building, even if wages and prices of materials and equipment are constant. Of course, they are *not* constant, and composition of output varies continually. A wage and price change accompanying differences in skills, quality, and capacity will have more complex effects than one that accompanies a simple change in scarcity of given types of input. But simple changes in scarcity are also rare. The closer one looks at a sample, the more each number in it seems to reflect a unique and accidental combination.

Nevertheless, for countries at all stages of development beyond a stick hut, two or three man-years (on the site and in the materials) seem to be needed to build an acceptable dwelling. Not by chance, two or three man-years of earnings and a decade or two are required to pay for one. Expenditures on materials seem to rise at the same rate as those on wages, so that wages tend to remain one-third of the combined total. That implies a unitary elasticity of substitution, meaning a relative 10 percent rise in wages makes a 10 percent cut in employment rational. In the present research, whenever a direct measure of elasticity was far from unity (below 0.7), a close look often found something hazy, even treacherous, about the original source of data.

The main question is not whether building technology allows substitution, but whether that substitution is desirable. In the long run, substitution is not just good but imperative. Without it, how could two or three workers build a house eight times as good in an advanced compared with a poor country? Productivity cannot rise if building methods do not move beyond handmade bricks and rough-hewn logs. And if productivity lags in one sector of the economy, who would want to work there if wages lag in proportion? Should wages not lag, then the price of dwellings would have to rise sharply compared with prices of other goods and services and make even an opulent society live in beggarly housing. (Unfortunately, that effect can also be due to other familiar causes.)

Having an opportunity to substitute is good, even providential, but every opportunity can be ill used. Just as lagging productivity in building or any other sector can harm a society's standard of living, so can productivity be raised prematurely. One can buy higher labor productivity at an exorbitant price. The capital that goes into equipment and productivity-raising materials could be used more effectively elsewhere in the economy, while the displaced workers could not.

No policy maker for the housing sector need be directly concerned with forbidding premature substitution. No guidelines need be drawn up and enforced to forestall the premature use of bulldozers, motorized winches, cranes, and mechanical plastering equipment. As long as unemployed workers are ready to handle shovels, push wheelbarrows, and pull on ropes at the going wage, that wage just has to be left low enough to keep all the gadgets from being cheaper. One cannot forbid the gadgets, because for some types of construction they may be required and because ways of substituting are too innumerable to be fully covered. Raise wages unduly, and builders will substitute, no matter what is forbidden.

The saddest part is that an elasticity of about unity keeps higher wages from improving the economic position of labor. If wages rise by one-tenth, and only 90 percent of workers keep their jobs, they may want to use their pay raises to help out the 10 percent thrown out of work, and will themselves be no better off than before. If the employed do not care about their jobless fellows, and would rather buy more for their own families, that is understandable, but is it a warranty of competence in wage policy from the social point of view? Social policy means keeping some people from hurting others, in this case, the poor from harming the poorer. Economic development begins when wishful thinking ends, here, when the technological imperative of substitution is accepted as a harness and not used prematurely as a yoke.

3

Cost-Reducing Innovations: Foundations and the Shell

Highlighting nothing but innovations in a discussion of technological change is like depicting the history of mankind as a series of noble battles — romantic. Those who are responsible for making buildings better and cheaper do not generally spend their time contriving grotesquely clever gadgets, designs, or formulas, waiting to cry "eureka!" before telephoning a patent attorney. They ask themselves not "what is new?" but "what is good?" because even that is not known automatically for each case from one's education or handy reference books. Like the family doctor, one diagnoses conditions to see what works. One does not vary the treatment for its own sake, but sometimes one must, and if the results are surprisingly good, one gives it a scientific veneer and publishes. Building researchers are thus more concerned with being constructive than with being original.[1]

Having said that, we proceed romantically to survey nothing but cost-reducing novelties. Both successes and failures will be treated since true learning is preserving the errors of the past. We shall fall far short of cataloguing all that has happened. Readers who wish to get to the heart of the matter without looking at every capillary along the way are strongly advised to move ahead to chapter 5, which attempts to draw statistically valid general conclusions.

Prologue

Reductio Ad Sites and Services

Anything novel that reduces costs is not necessarily a cost-reducing technological innovation. For example, one can reduce the cost of a dwelling by eliminating paint, doors, and windows. Are shack builders innovating when they omit plumbing facilities? Omission usually implies postponement and later informal installation by the occupant. Such installation is particularly hard for plumbing and roofing, so that some educated innovators would reduce the house by everything but these two components. Obviously, there also has to be an urban site with connection for plumbing. In fact, that is *all* there has to be according to the popular sites-and-services approach. You reduce the cost of the house by eliminating the house. Clever and useful, but not technological.

A technological cost reduction lowers cost for a *given unit* of output, not for a unit that shrivels and disappears. At least if the dwelling unit shrinks, cost must fall even faster and reach zero first. The best approach is to think in terms of cost per unit of housing *service,* with each dwelling providing a flow of such services in the form of shelter from climate, privacy, security from theft, space for activities, comfort, prestige, and all sorts of other amenities. The absence of windows or plumbing means the absence of certain housing services that some families would like to have and pay for and others not.

Price-Raising Cost Reductions

Logically, we should also consider any potential increase in housing services that is greater than the associated increase in costs of a cost-reducing innovation. Cost per unit of housing services falls. The problem is that housing services are rather intangible, and that those who should know most about them, the architects, have a chronic tendency to overrate the flow. The client's financial maximum is universally the architect's minimum. His professional conscience does not allow him to withhold the extra bit of design (and associated services) from the client. Indeed, he tends to feel that the extra bit ought to be imposed by law to protect the client against himself and rash scrimping. As one architect told me in July 1973: "We are architects, and we are mainly concerned with space. We are not economists. We are architects. Economic problems are for other people to solve. If it costs 16,000 dollars, you must find the money. You have to respect architectural principles, or it is not a house."

As an economist, what I respected was his concern for economic principles, the division of labor. But I think one had better put a budget constraint on the architectural conscience, on what can be accepted as a price-raising yet cost-reducing change. Perhaps a price rise of one-fourth should be the limit. Such a move is generally countered by architects with a minimum standards constraint. These two constraints can be reconciled for different per capita income levels and patterns of income distribution by means of projected stock-user matrices.[2]

The only kinds of price-raising cost-reducing innovations that will definitely be included here are types that do not raise the flow of housing services per year at all — no more space, heat, light, comfort, or prestige at any given moment. All they do is increase the years or number of moments during which the flow can occur. Obviously, I am referring to innovations that raise durability or maintainability, innovations that most people would call quality raising. Higher durability lowers the need for maintenance, and better maintainability makes maintenance cheaper and more convenient. Replacement can be postponed and even limited to components. A high interest rate for discounting the future gives maintenance innovations the edge, while a low interest rate favors durability. If the innovation guards against uncertain floods, hurricanes, or earthquakes, its value should be lowered by a probability or risk factor.

Risks and Profit

Other risks should also be pondered when judging the costs of an innovation. *Production risks* are the chance that the component or structure will collapse or function badly in a physical way. If this chance is low, but designated occupants reject the design because of habit or prejudice, there is a *customer risk.* If the habits and prejudices are mainly those of passers-by, then invisible innovations have the best chance. The rich can most easily afford to be visibly innovative because changes in their houses are not likely to be mistaken for contemptible economy measures. One would think that the poor could not afford *not* to be innovative; but, in fact, their attitude tends to be: "We may be poor, but we're not crazy."

Interference risks are threats from hostile government agencies, competing firms, or workers whose activities may become less remunerative or obsolete. Large-scale innovations are also subject to *timing risks,* possible failure due to sudden but temporary yet fatal shortages of credit, foreign exchange, or some other input. A synonym for this risk is "bad luck."

Clearly, one should also note whether or not the cost reduction is due to the use of less equipment, less skilled labor, less foreign exchange, less transport, or cheaper materials. When a saving in some factors goes with greater use of others, relative input prices obviously determine the net effect. Changes in the speed of construction may be important -- usually for socially unimportant reasons.[3] One should also ask if economies of scale are needed, specifically, a minimum volume to make the innovation feasible. This need for volume may give scope to "bad luck," as mentioned above. Sometimes inferior but capital-intensive methods are inflicted on an economy in order to overcome price increases due to bottlenecks. Whether successful in this aim or not, the guarantees and government commitment to such changes tend to deprive an economy of flexibility. The point is, costs have a time dimension.

Finally, researchers will be wise to remember that most cost reduction is likely to mean less price reduction than profit expansion. When the novelty has a monopoly, a 10 percent price advantage over the established product will usually provide enough sales for a business without major interference risks. The remaining cost reduction goes into profits.

The Agenda

A series of innovations can be discussed in a variety of sequences. Two poor choices would be chronologically or alphabetically; in order of importance, either according to profitability or to their pathbreaking intellectual character, is a possibility. Another is by origin — type of country or sponsoring institution. One could group them by their knowledge characteristics, that is, all those that adapt methods from advanced countries in one category, and all those that improve local traditional methods in another. Some would be dependent on further scientific exploration, others not. Some are mainly changes in organization or procedure. One could take up all the sitework innovations, then all the material changes, then design changes, then settlement patterns, then various combinations of these four.

Compared with that idea, the actual procedure here will be quite humdrum. We begin with new ways of making foundations (from

Mexico, India, Jamaica, and South Africa). We then put up the walls in three sections. Walls can be made out of little pieces, such as bricks and blocks, or big pieces, such as panels. In fact, large unconventional wall components have received so much attention that we have included a separate iconoclastic chapter 6 on industrial systems building. Walls can also be poured or sprayed with liquids that harden.

After the walls are up, we put on ceilings and roofs (with ideas from Italy, Kenya, Egypt, India, and South America). There are a few novel ways of installing floors or utilities, which will be mentioned at the beginning of chapter 4, and a larger number of additional materials innovations (from New Guinea, Malaysia, India, Israel, Egypt, and even the United States).

Described next are various novel onsite procedures and some changed general management methods. Alterations in floor plans or design that do not change materials or working methods but nevertheless reduce costs (without reducing the flow of services) are then discussed. A general evaluation and conclusion follows.

Foundations

To begin a discussion of buildings with the foundations should not be regarded as arbitrary. To regard the foundations as unimportant simply because they are invisible is literally most superficial. Indeed, Dinesh Mohan, Director, Central Building Research Institute of India, considers the development of underreamed piles for foundations his institute's most important achievement in its first 25 years.[4] Nor was this the only foundations innovation developed in India. Soil conditions differ throughout the world and even within small countries, and no research institute can omit their study. Ideas for better foundations are a common result.

The innovations affect design, sitework, or materials. They range from "off-shelf" applications of something foreign and slight improvement of traditional methods to science-based innovations and complex adaptation of advanced techniques from abroad. Most decrease the need for construction labor. Some reduce all costs, and others involve trade-offs. Most improve some factor other than cost-durability, quality, or at least speed of installation. Some change the materials used, some change the sitework procedures, and some alter the design.

The only innovation that I have encountered that increases the amount of labor per foundation is the *hyperbolic paraboloid shell founda-*

tion developed by Felix Candela in Mexico in the 1950s. This type of foundation saves concrete, but because of its complex shape requires more labor and more skills. The foundations are particularly suited for column footings in loose poor soils where conventional footings perform badly. From Mexico the innovation has spread to Kenya, India, and elsewhere. Relative costs were studied in India in four separate urban areas. Labor costs for earthwork rose by 25 percent, but total costs nevertheless fell by 22 percent or more when bearing capacity of the soil was less than ten tons per square meter.[5]

This type of foundation was a successful labor-intensive, science-dependent innovation. The characteristics of the hyperbolic paraboloid piles contrast sharply with those of *bored foundation piles* developed in Jamaica during the years 1962–1965. This latter type of foundation was designed to support low cost (£1,500 sales price, less half for land) houses of 45 square meters of concrete shell construction. Ten piles nine inches in diameter are sunk 1.8 meters into the earth and terminate in a 5.40 × 5.55 square meter pile head upon which the floor panels sit. A truck borer bores the pile holes in about 2½ minutes each. Then adjustable fiberglass forms are placed over the holes, and concrete is poured. A reinforced cage through the pile head is capped off with two flat welding plates. Use of all this capital equipment and materials minimizes the need for supervision and site grading. Variations in grade can be countered by simply lengthening the piles above ground. Although the houses typically rest 45.72 centimeters above ground, allowing underhouse ventilation, they are earthquake and hurricane resistant.

Reduction in the cost of materials and labor is the principal advantage of this innovation, with an increase in speed secondary. Its characteristics are sufficiently novel to classify it as adapt-advanced. This category refers to any modern novelty from an industrialized country that requires engineering adaptations to local conditions. It was successfully used in one project of 1,900 dwelling units.[6]

The use of circular rather than square footings also has been explored in Indian research on *reinforced concrete circular column footings*. Tests of square footings showed that radial cracks developed due to circumferential bending moments. The circular footings were designed on the basis of the theory of plates and were found to need 50 percent less steel than the conventional type. For the total cost of footings, the saving is 7–8 percent.[7]

Making footings circular instead of square is a minor change compared with *underreamed piles,* perhaps the greatest achievement in

Indian building techniques. Before these piles were developed, soils susceptible to a high degree of swelling and shrinkage with changes in moisture were a constant source of trouble. They made buildings crack. Beginning in 1955, the Central Building Research Institute (CBRI) studied the principle of anchoring buildings at a depth where ground movement would be negligible. An earth auger was developed and patented for boring straight vertical holes. The bases of the holes are then enlarged by a special underreaming tool developed by the CBRI, patented, and now commercially manufactured. The reinforced piles with their bulb ends are cast *in situ* into the bore holes. For the kinds of soils involved, these foundations are 20–30 percent cheaper than traditional ones. By 1969 over 20,000 houses had been built with this system. In the meantime, multireamed piles had been developed for multistoried buildings. The Ethio-Swedish Institute of Technology has applied the system in Ethiopia.

This innovation should be classified as science-dependent because new knowledge of a general character had to be developed to make it possible. It reduced all costs and raised quality, especially in the sense of durability and maintainability.[8]

These were not the only Indian ventures into foundations. *Soil cement foundations* and *road pavement type foundations* were two other successful ideas. Both may be classified as improving traditional technology and as reducing material and labor costs. The CBRI experimented with the soil cement foundations and found that their cost with 6 percent cement came to about 29 rupees per cubic meter. Strength was four times that of conventional concrete, which cost 43.3 rupees in the early 1960s.[9] The road pavement type foundation was promoted by H.D. Gupta of Udaipur. He noted that in conventional single one-story houses the masonry below plinth level constituted one-fifth of total building cost. That masony was eliminated, and a 58.125-square-meter house was built on a substructure resembling road pavement. Total cost was 4,400 rupees, or 15 percent of what might have been expected.

Nor has India been alone in delving into the foundations. At Capetown University, South Africa, in 1958, Stanley Amdurer thought of a new technique for creating *artificial sandstone foundations* in sandy soil. This method puts a chemical cementing agent into existing sandy soil by means of ground water. Ethyl silicate or N-Methylene-bisacrylamide is injected into the soil via a number of standpipes. Well points extract the groundwater to draw the chemical in. An area of 27.90 square meters can be covered by two well points and twenty standpipes in a circle. For full strength, the process takes about two hours.[10]

Bricks and Blocks

Once there are foundations, one can put up walls, and after that one can try to make them more cheaply with innovations. The last step is difficult because making walls is so easy. Mankind emerged from caves (with their infinitesimal construction costs but clearly excessive wall space) and over the centuries has made artificial walls out of anything that came to hand — rocks, sticks, leaves, orange crates, and oil drums. For milennia chemistry was in a rudimentary state, and only four elements were identified: earth, water, air, and fire. These were combined to make the brick. Flat surfaces all around were the attribute of the brick that allowed almost anyone above the age of two to make walls by setting them neatly one on top of the other. Until people wanted windows and arches, architects and professional bricklayers were unwelcome.

Despite or because of the difficulty of improving something already cheap and adequate, more innovating continues to go into walls than anything else. I have found more attempts to improve bricks and blocks, the cheapest and most adequate wall materials, than any other kind of innovation. Nevertheless, there are enough attempts to make walls with unconventional panels and systems that they will be treated separately in chapter 6 and Appendices C and D. Fluids may be used to pour or spray walls, as we shall see. The British have gone farther and suggested that "air is an excellent building material for the construction of walls."[11]

Although cost reducing at times, none of the wall innovations studied were labor using, and most claimed to be quality improving. To assess the quality claim, one must know what a wall is expected to do. One reasonable function is for it to accept a nail so that a picture or mirror can be hung. Another is to control the transfer of heat and noise. Resisting fire, wind, rain, and the rising damp is another set of welcome functions. Above all, a wall has to carry vertical and lateral loads, including itself, without falling over or cracking. Hence, apart from their flatness and rectangularity, the compressive strength of bricks is their most important feature.

A column that is 30.48 × 45.72 centimeters at the base and 6.096 meters high weighs about 1.5 tons. The bottom bricks are subject to a compression of about 15 psi (pounds per square inch). If a safety factor of 10 were to include the roof and other dead or live weight, a strength of 150 psi should be adequate for much dwelling construction. Burnt clay bricks have a psi ranging from above 1,000 (hand molded) to above 2,000 (machine molded). An innovation that saves fuel, clay, and equipment can eliminate psi only up to the point at which the secondary functions of a wall are not impaired.

Brick and block wall improvements are organizational, off-shelf, adapt-advanced, science-dependent, and improve-traditional in character. These terms have been defined in a rather self-evident way in the preceding pages, but a summary can be found on pages 86–87 in chapter 5. For bricks and blocks, the improve-traditional category is perhaps the most important. Some innovations in this area raise and others lower the cost of materials and equipment, but, as already noted, none raises the cost of labor inputs compared with uninnovative brick walls per physical unit. They are employment generating only in the important sense of keeping brick walls competitive with panels and housing competitive with other more capital-intensive products.

An important organizational innovation is the secondhand brick or block. When a building is demolished in Latin America, subcontractors chip the mortar off usable blocks and bricks (those with flat sides intact) and sell them to the poor. Usable roof tiles are sold to the rich. Other organizational innovations will be deferred to a special section on sitework methods. Here we shall consider, first, different brick and block materials; second, variations in size; and third, alternatives in shaping and treating to produce those sizes.

Changes in Materials

In some areas, the *concrete block* has not yet reached an equilibrium level of use, given potential price and capability, compared with bricks. For example, in Brazil concrete blocks are widely used for housing in São Paulo but not in Rio de Janeiro. Block houses need no plaster, unlike common bricks that are not weatherproof. Block houses built in Rio de Janeiro in the 1950s have survived well and may have cost 30 percent less, but for some reason block production was greatly curtailed at one point and never resumed.

A more common target of research has been *stabilized earth bricks* or blocks. These eliminate the expense of ovens and fuels. The sun is used instead. During the 1950s much of the research centered on cement or lime as an additive, but in the 1960s attention shifted to bitumen. A project in Iran showed that adding 20 percent lime putty to soil produced bricks with a psi of 175 and with excellent performance under spray and immersion tests.[12]

Other early work was conducted in the West Indies. *Megcrete blocks* were developed in Barbados in the early 1950s. Megcrete is six parts pressed bagasse from sugar cane and one part freshly slaked lime. The blocks are actually more like panels in dimension, and since they contain no soil they are more a substitute for timber, except from the termite's point of view. In the 1950s they were supposed to make houses cost only 12 shillings per square foot, compared with 14 shillings for timber houses built by the owners (18 shillings if government built) or 15 shillings for a coral limestone house.[13]

Similar in spirit are the *fired bagasse-clay bricks* of Antigua, West Indies. These mixtures of one part clay and one part bagasse (10:1 by weight) are genuine bricks. Since the material is 20 percent lighter than clay bricks, some roofing tiles were made, but these had the disadvantage of being porous. Some of the bagasse-clay bricks can use inferior clay without cracking, but their shape is too poor for use anywhere but in invisible interior partitions. This attempt at innovation may be classifed as interesting, but inconclusive.[14]

Discussion of the *black cotton soil bricks* of India no longer can be postponed. They were developed in 1965–1966 by the Central Building Research Institute at Roorkee (CBRI). Central and western Indian soil is terrible for bricks; it expands and shrinks and contains nodular lime. Nevertheless, with coal ash as an additive (itself an innovation), conventional bricks could be made. But that option was not nearly good enough for the CBRI. The matter was studied scientifically, and a new process was developed using calcinated clay as an admixture, called "grog." It raised compressive strength from 800 psi to over 2,000 psi. Cost was a little higher than conventional bricks, Rs. 49 compared to Rs. 47 per thousand. But the bricks were good enough to sell, and anyway, coal ash was expected to rise in relative price.[15]

Bitumen stabilized bricks were also known in the 1950s, and the American Bitumuls Company of San Francisco had a patent for one process during that decade. Later, many countries experimented with similar ideas. In India someone found that 26.495 liters of asphalt could make 2,000 bricks. Cost including delivery of bricks within half a mile would be 26 rupees per thousand, compared with 60 rupees per thousand for burnt bricks. The cost of 3 percent soil cement bricks would be about the same (Rs. 25) if made with unpaid self-help labor, but these bricks would need plastering. The saving was 22 percent in the experimental construction of a school.[16]

In both India and Peru, bitumen stabilized bricks are being developed in association with the International Institute of Housing Technology at Fresno State College, Fresno, California. The Indian research has been carried on at the Building and Road Research Laboratory in the Punjab. Some experimental structures have stood for ten years and weathered better than cement/lime blocks. "But for some reason, these new techniques and materials have not been given due trial in the field for the general benefit of the public. There is no longer any dearth of know-how, what is required is an initiative on the part of the authorities to push the technique in the field in the form of a crash programme."[17] Perhaps the authorities had a hunch about the timing risk of introducing any oil-based product.

The Peruvian project, like the Indian one, uses only 1 – 1.5 percent bitumen, compared with 5 percent in California. Holes are left in the blocks for bamboo reinforcing against earthquakes. After the bamboo is inserted, the holes are filled with the same stabilized adobe. Hexagonal floor tiles that can be polished have also been developed. Cost of a house is estimated at 1,000 soles per square meter (US$2.30), or 40 percent of the conventional cost.[18]

For any house built before or despite these innovations, with unstabilized sun-dried brick walls, an *asphalt based plaster* was developed in India that could bind with such walls. In the mid-1960s, the cost of covering 9 square meters with 1.27 centimeters was about Rs. 7. The mixture consisted of 3 percent liquid asphalts, 25 – 30 percent sand, and red loamy soil. The National Building Organization found coal tar even better than asphalt.[19]

Changes in Dimensions

Besides bricks, walls consist of mortar, so one innovation is to *eliminate the mortar.* A method of doing so with *interlocking blocks* was announced by Educational Design, Inc., and demonstrated at the Proyecto Experimental de Vivienda (PREVI), sponsored by the United Nations Development Program, in Lima, Peru. These interlocking blocks, called the EDI Thermond system, weigh 5 kilograms. Reinforced concrete is needed only at the corners and upper edge of a wall. Up to three stories, the walls are self-supporting. The blocks can be made in a hand mold at the rate of 400 per day. The system has been used for low cost housing in the southern United States and Mexico and is supposed to save 15 percent at Latin American wage rates.

Other types of self-aligning blocks were used in the late 1950s in

Guatemala. There, an Inter-American Cooperative Housing Project had found that these blocks were cheaper than *in situ* poured reinforced concrete, even if modular plywood formwork was used and reused up to twenty times per form.

Self-aligning blocks have also been used in Tunisia under the name *bloques africaines*. They are hollow concrete blocks 50 centimeters long with grooves and protrusions that allow setting in place quickly without mortar. Some 800 dwellings had been completed by 1974 at the Ibn Khaldoun Development at Ras Tabia, near Tunis, and about 4,000 additional units were planned. Initially, the blocks were to be handmade. Eventually, however, a German machine for mass producing the blocks was installed at the site. The blocks had been specified by architect André Ehrman of the consulting firm Société Centrale pour l'Equipement du Territoire. The Ras Tabia Project is an imaginative settlement of fairly low cost housing that combines modern and traditional Arab designs, and it is one of the most labor intensive that I have visited. For example, roofs are the traditional North African vaults. Nevertheless, costs doubled from original expectations due to rising wages, materials scarcity, and delays. By extending mortgage maturities from 15 to 25 years, the same families for whom the project has been intended, and who had begun payments, could still be accommodated. The project had been financed by a loan of US$10 million from the Agency for International Development under the guarantee program.

The developer of the EDI Thermond System, Christopher Alexander, also had another idea: *molten sulfur and fiberglass* for reinforcing. To molten sulfur or sulfur ore, one adds dicyclopantadiene (a plasticizer), milled glass fiber, and talc powder. When this mixture is sloshed on walls in place of mortar, about one-fifth of the construction costs of a small house can be saved. After experimenting on 40 houses, the Colombian Instituto de Credito Territorial proceeded to use it on an additional 900. According to the Agency for International Development, which hired the Southwest Research Institute of San Antonio, Texas, to develop the process, Botswana and Tanzania are trying it now.[20]

Most changes in dimensions are less elaborate. The brick or block is enlarged, holes usually are inserted without lowering strength, and the materials are given a name like King Kong, Modular, or PREVI. Since perforation requires equipment, the omission of holes is capital saving and materials using. Research and analysis at the Building Research Station, Lahore, Pakistan, showed that even a small change can make a big difference economically. The Pakistanis decided to make bricks 2.54 centimeters shorter and 2.54 centimeters higher, a *modular brick*, 8″ × 4″ × 4″. Per foot of height, only three, not four bricks, are needed. Since bricks are laid in double rows or at right angles to the wall, walls would be one-ninth less thick, a saving in materials. Furthermore, 8 percent fewer bricks would be needed, and productivity of labor would rise by about one-quarter. Bricks were also expected to be 12 to 20 percent cheaper. The government and the Pakistan Standards Institution accepted the new size, but for the conservative brick industry the change apparently was too radical. Except for two trial runs, no modular bricks were produced between 1965 and 1970. Undaunted, officials of the Building Research Station still declared that "the 8 inch brick may well be the future size of brick in all countries."[21]

Alternative Brick Production Methods

Modern brick factories cannot undersell bricks made with traditional methods in poor countries. Typically, a box with two brick-sized compartments is filled with clay, pushed in by hand, and levelled off with a stick. Then box and clay, weighing about 14 kilograms, are turned upside down, and out come the bricks. A good worker can make 800 to 1,000 per day. After sundrying, the bricks are fired for a week in crude trapezoidal ovens. Cost per brick will be one-third less than the average common brick in the United States.

The Methods Engineering Council of Pittsburgh, Pennsylvania, estimated in 1955 that for a tropical or semitropical country a *minimal modern brick plant* would cost $360,000, not including land or working capital ($77,000). At 1972 prices, this amount would be $640,000 (plus $136,000). The plant would employ 50 workers, from the manager down to the quarry power shovel operator, but not including salesmen. Per week, 240,000 bricks would be made, or 12 million per year.[22] Cost per brick in 1955 would have been 2.1 U.S. cents, implying a selling price of about 4 cents. The European inventions behind this sort of plant were made in England in the 1830s. They have been improved since then.

In Lima, Peru, such modern brick plants first appeared in 1960, and their market share stabilized at around 30–40 percent. Precision cutting with wires gave the bricks more accurate dimensions, and more careful mixing and firing led to greater strength. Consequently, these bricks could sell for 12 percent more (2.4 U.S. cents) than handmade bricks in 1968. (By 1971, prices had risen 19 percent, and after that they were nominally frozen.)

The enthusiasm for mechanizing and automating can easily go too far. I saw one plant that had installed automatic mixing, grinding, extruding, and wire-cutting of bricks. The furnaces had oil injected from the ceilings with a German machine that measured the amounts automatically and travelled from compartment to compartment. The day I was there an Italian automated storage-handling machine was inaugurated. The heart of this machine was an indexing mechanism for four positions. In one position a wooden pallet would be swung around to the next position and be scooped up and set into a travelling rack for drying bricks. This rack would slowly be filled with wet bricks while another was being unloaded at the third index position. In the fourth position dried bricks would be scooped on to a conveyor belt going to the ovens. Full wet racks travelled along tracks to vacant spaces in the storage area, and full dry racks rolled to the emptying side of the indexing machine. A console with 40 knobs and 20 lights controlled all this. Not including assembly and installation costs, the machine had cost US$57,000. With it, three workers could take the place of seventeen.

Just before the inauguration, a worker climbed up one rack and tied on a bottle of champagne. The families of the owners and invited guests gathered around while an old priest read from a gold-leafed Bible. He said: "We ask a blessing for this machine which has been installed by the father of a family. It can be a good example to all of us. I beg Heaven with these blessings that it may run with perfection." He took his silver sprinkler and scattered holy water on the conveyor belt, on the cutters, the extrusion machine, the mixer, and even further back on the grinder — everywhere except the last stage, the new part, where the bottle hung on the rack. After the owner's youngest daughter had broken the bottle, the machine started in its clattering way, the indexing device hopped around, and lights blinked on the console.

Five years later I saw the owner again. I asked about the machine. "That was a bad one," he said. "I had my doubts about it all along. It couldn't handle the volume of bricks we were feeding it. Nothing but interruptions and breakdowns. I was losing money. After five or six months, we dismantled it. At half the speed it might be all right."

We drove to his brickyard, and I saw that the output from the conveyor belt of the wire-cutting machine was given to men with wheelbarrows, everything going very smoothly. Later, I saw that the automatic oil injection system was working improperly at the ovens because the insertion tags had not been cleaned. Inside one oven a stack of hollow ceiling tiles had crumbled because they had been laid in while still wet. At the mixing stage, the sieved sandy clay fell between the slots, instead of on the conveyor, while stones and rubble fell unwanted into the grinder, rattling around. Productivity depends more on management than innovation.

In India, mechanized clay brickmaking began in 1964, and soon 20 plants were in operation or on the drawing boards. The CBRI developed a machine for producing about 3,000 bricks an hour at a cost less than imported machines but not nearly less than hand labor. The hope is usually that more accurate bricks can be placed and finished with plaster at a saving rate that compensates for the initial extra outlay.

Another type of mechanized brick factory produces the *sand-lime brick.* This type, as the name hints, does not use clay but sand and lime. One can hardly describe it as a great novelty, since a Mr. Kent patented the idea in 1810. A drawback of his method was that bricks took seven months to harden. Not until the invention of the steam autoclave for hardening and of another machine for pressing bricks into molds did sand-lime bricks become commercially feasible. The first full-scale plant began operations in Germany in 1898.[23] An advantage of sand-lime bricks is their creamy whiteness, which makes them acceptable as facing, saving plaster for owners who loathe brick-red (or every other color).

Sand-lime brick production did not begin in developing countries until much later, for example, in Mexico in 1950 and India (Kerala) in 1964. By 1964, 8 percent of bricks made in Mexico City and environs were sand-lime.[24] Peru did not acquire a sand-lime plant until 1957.

The Peruvian case may illustrate the problems that can arise when introducing a well-established process from abroad, or the conversion of production risks into customer risks. For a comparable size, sand-lime bricks at first sold for the same price, but within five years a 24 percent differential was charged. After all, their greater regularity allowed a 24 percent saving in labor and materials in plastering (as a share of total wall costs). Costs fall by almost 40 percent where the white bricks were used as facing. But troubles developed, and eventually the producers had to lower the price back to the level of clay bricks. Sand-lime brick walls had cracked. The bricks were all right, but the Germans who set up the factory had not told the Peruvians that sand-lime brick walls need more expansion joints and must be made with mortar containing about 20 percent lime, not with conventional one-to-five cement-sand mortar. The needed lime was not even produced in Peru until 1961. In 1968 I found a continued prejudice against sand-lime bricks among the majority of a sample of contractors,[25] and even in 1973 I found that the product had not recovered its past standing.

The last category of innovation to be mentioned in this section can be certified as genuine intermediate technology: *the hand-operated block or brick machine.* Perhaps the most famous of these is the CINVA-Ram machine designed by a Chilean engineer, Ramirez, for the Inter-American Housing Center in Bogota in 1957. The machine is small, weighs only 63.42 kilos, and can be operated by one man. Its capacity with two men is about 300 soil cement blocks per day, using 150 kilos of cement and a lot of soil for a 5 percent mixture.[26]

In the West Indies, 200 pilot project houses were built with CINVA-Ram blocks in 1964 and evaluated in 1970. Some had eroded and others were satisfactory. A variety of conclusions emerged: Silt content of the soil should be less than 10 percent; cement content should be between 5 and 10 percent, no more, no less; minimum thickness should be 15.24 centimeters and strength should be 300 psi, 250 psi for bigger blocks; and blocks with over 8 percent water absorption should be waterproofed and should not be used for foundations in rainy areas. The damp-proof course should be at least 7.62 centimeters above ground level.

Hand-operated machines have also been developed in Great Britain, South Africa, Pakistan, and elsewhere. The Pakistani machine costs Rs. 500 and makes modular bricks, two at a time, with a semidry mixture. Initial trials showed that a crew of four could make 2,000 bricks per day at a 1970 molding cost of Rs. 20.[27] By attaching a simple hydraulic handpump, a similar British hand-operated block-making machine (costing £100 in 1968) attains strengths of 1,560 psi; the cement-sand-aggregate ratio is 1:5:5.

Surface-Bonded Masonry

An innovation that apparently has great potential is bonding masonry by brushing on molten sulfur instead of putting mortar between the joints. To 100 pounds of sulfur, three pounds of a plasticizer, dicyclopentadiene, must be added, as well as 5–33 pounds of glass fiber, asbestos, or talc. Using only five pounds of Colombian asbestos, the strength of a 2–4 millimeter thickness is 500,000 kilos per square meter (710 psi). To double this strength, one must use either 20 pounds of asbestos or 7.5 pounds of talc and three pounds of glass fiber. Standard masonry walls are not this strong. In fact, lintels can be made by bonding blocks in the form of a beam and lifting it into place. This method was developed and tested by the Southwest Research Institute of San Antonio, Texas.

In 1977 the Agency for International Development sponsored trials of the method in Cartagena, Colombia, under the auspices of the Territorial Credit Institute. Four hundred dwellings with a floorspace of 30 square meters were built out of concrete blocks and included a toilet, wash basin, and electricity. Half a ton of sulfur, costing US$60.00, was needed per dwelling. Compared with conventional construction, costs fell by about one-third, from US$40.00 per square meter to US$27.00.[28] Fire tests with burning cooking oil have shown that the sulfur burns away in an hour and that fires then go out. Nevertheless, a risk remains, and use on two-story buildings has been avoided.

Poured or Sprayed Walls

Since pouring or spraying liquids into tubs is even easier than lining up bricks, someone was bound to think of that as a way of making walls. The problem was eliminating the tub without losing rigidity. Needed was a liquid that would harden. Nothing very suitable was available (other than water in arctic zones) until Portland cement was invented in the 1820s. During the 1860s gifted Frenchmen began reinforcing concrete with bars, and, *voilà*, a new way of building! Others had thought of concrete as just another plaster or way of fireproofing.[29] In the 1880s the method spread rapidly in Northern Europe and the United States. It was used in India before World War I, and in 1922 the John C. Gammon enterprise pioneered there with prestressed curved shell roofs. Many years later, Gammon told me:

> No, there was no problem about quality. Workers there were cheap and we had them stomping for hours and hours. As we built our organization, we found supervisors, some of the best in the world. We used steel scaffolding and moved it from place to place. It was like working from a floor. Also steel shuttering. But for the walls we always used traditional wooden scaffolds, so cheap we didn't include it in our estimate.
>
> In 1921 a drunk foreman stopped six feet short with his reinforcing and that part of the building collapsed during construction, not the whole building. No other buildings collapsed for me, but sometimes I lost money. People had their doubts, but I knew the principle was correct.

So we can hardly treat reinforced concrete as anything but a well-established technological option; no mysterious element of novelty remains about the basic idea. Research continues into the possibility of using limestone or sea shells with this or that impurity for cement, but this will not be treated here. We shall take up a few ideas for novel types of formwork or shuttering and others for better spraying or pumping. Ways of making the entire shell, including the roof, will be left to the next section.

As a rule of thumb in developed countries, in relation to total cost of a concrete wall, setting up and dismantling the formwork costs 40 percent, putting in the steel reinforcing costs 30 percent, and pouring in the concrete costs another 30 percent (labor and materials combined in each case). Thus, the formwork would seem to be an obvious target for innovation.

Using expensive metal instead of cheap wood seems to be a step in the wrong direction, but nevertheless it is one often taken. Some Peruvian firms began using metal forms in 1958, probably because they had a stock on hand from making canals, tunnels, or some other highly repetitive operation. Such expensive items are frequently rented, rather than owned, in order to get more volume per form. They are off-shelf, capital-using, labor-saving changes.

From metal forms that had to be reassembled as each new dwelling was built, the next step was permanently assembled plates, a *single megaform* for the walls of an entire dwelling. Wallace Harrison invented such a form for a two-bedroom house, and the International Basic Economy Corporation (IBEC) applied the system in Puerto Rico in the 1950s. A crane would move the big form from site to site. A production risk of unexpectedly long curing time showed up, as well as a customer risk due to the lack of variety. The attempt was abandoned in Puerto Rico and tried again without success in Chile.

Another materials-using, labor-saving innovation being examined in Peru is *lost formwork (encofrados perdidos)*. Lightweight muracret panels are set up and supported, and the concrete is poured between them. Bonding is good, and the panels are left as part of the wall, thus saving dismantling labor.

A different set of innovations makes the handling of wet cement easier. One of these, called *situfoam*, was used by the British firm George Wimpey and Company in building 1,000 low cost houses in Baghdad, Iraq, in 1957. Compressed air and a foaming compound were mixed with liquid cement and pumped through a hose into aluminum alloy formwork. Further finishing was not needed. This innovation substituted materials, equipment, and even foreign exchange for labor. Such houses were also built in Kuwait, Malaya, and Indonesia.[30]

Once one starts pumping cement, *pumping aids* become a possibility. One product for this purpose was developed by the Construction Products Division of W.R. Grace and Co. and called Darex Pumping Aid. It lubricates the mix and lets the concrete flow faster. Depending on the building design, from 10 to 40 percent of labor can be saved for every 0.765 cubic meter of concrete placed, according to Grace.[31]

During the 1960s a product called Sheltron came along that is not much different from situfoam. A lightweight concrete is made even lighter with a foaming agent ("Vinfoam" chemicals and an accelerator). The bubbles raise volume by half. At very low pressure, the mixture is sprayed on mesh-covered steel reinforcing bars in thin layers. Highly skilled technicians are not needed for this process, but quality control is important. This is another science-dependent, labor-saving innovation with potential.[32]

The idea of spreading concrete on wire mesh without formwork (*ferrocement*) is an old one, dating back to a boat built by Joseph-Louis Lambot in 1847. At the Horse Bridge People's Commune near Shanghai, boats have again been made that way since 1964. Ten teams of 50 people build one boat each per day, charging 750 yuan (US$330) for the six-ton size and making a 7 percent profit. The boats weigh two tons, are reputed to have "ten superiorities," and are most commonly seen carrying nightsoil along the Horse Bridge Commune canals. At least 18 other developing countries have made such boats, clearly, an idea whose time has come.

In the Soviet Union, ferrocement has been used in wine storage tanks and for roofs. The architect Nervi built walls and roofs with ferrocement in 1945. In Thailand, Ethiopia, and New Zealand all kinds of silos and utility buildings have been made with ferrocement. So why not housing? In 1973 an *ad hoc* panel in the United States recommended the establishment of a "Committee for International Cooperation in the Research and Development of Ferrocement for Developing Nations" and an "International Ferrocement Information Service" which could "help to avoid repetition of several hapless ferrocement enterprises of the recent past."[33]

Roofs and Ceilings

Since panels and systems-building are reserved for a separate chapter, the discussion can now turn to ceilings and roofs. A house without a roof is normally considered ill-designed regardless of price, and nothing in housing is as disappointing as a roof that leaks, burns, or collapses. Yet, no housing component is more difficult to install, or consequently more expensive. Roofs should be produced out of local materials that are easily cut, mixed, poured, or assembled. They should last two decades without repairs, absorbing wind but not rain or solar radiation in the tropics. Thatch and wood serve well in the village, but in the city they do not come up to the minimum of one-half hour of fire resistance. Disastrous fires in the self-help areas of Hong Kong, Singapore, and Kuala Lumpur (among others) have been the result.[34]

The normal fire resistant urban roof has consisted of burnt clay tiles, concrete, asbestos cement, aluminum, or corrugated galvanized iron sheets, often secondhand. Of these, the last is the cheapest. In Singapore in 1962, concrete roofs cost about 16 percent more, and tile roofs 87 percent more, than corrugated iron roofs. In Accra in the same year, concrete roofs cost about 47 percent more and tile roofs 83 percent more.[35] Since the minimum price for a roof was about US$8.28 per square meter covered, that was the price to beat with innovations.

The innovations of the past two decades began with different types of formwork and beams to support concrete ceilings poured *in situ*. Later came suggestions for weird shapes and strange materials. As usual, most of them neither can nor ought to be mentioned here, but enough will be said about ideas and experience with Italian, Indian, Peruvian, Egyptian, French, Colombian, Pakistani, Kenyan, and Israeli roofs to cover the topic except for one omission. Not a word will be said about slabs, except that they go with the disdainful chapter on industrialized systems building.

Ceiling Supports

Using *metal instead of wooden forms* while pouring a ceiling is not exactly a bold leap forward, but in Peru it was not done until 1951. Compared with using wooden formwork and supports, about one-third of the labor is saved. A little cement is also saved because of the greater regularity of the metal surface. Nevertheless, the improvement seems marginal. In 1968 I found that scarcely half of a Lima sample of contractors used metal forms, and in 1973 I revisited one of the largest builders and found that he had shifted to steel supports and crossbars on which he laid the wooden forms. He had bought or rented no metal plates because "labor is too cheap."

Instead of casting a solid slab, one can *cast bars* with reinforcing and put hollow tiles between the bars. An Italian innovation, materials saving and labor using, was to prefabricate the bars themselves with hollow tiles, cement, and reinforcing. The method spread to East Africa around 1950 but was still being mulled over in India in 1960. Among the advantages was lighter weight for the entire structure, meaning cheaper foundations. Compared with a solid slab, the saving was about 19 percent. Especially economical was the 40 percent saving in cement.[36]

In the United Arab Republic, A. el-Arousy designed concrete beams that village builders could manage. A beam with notches would go on the top of adobe walls. The flanges of ceiling I beams would go into the notches, that is, the I's would lie flat. Cracks between the I's could be covered by inverted U plates. To make a sloping roof to shed rain, one wall could be made higher than the other. This simple roof was far less flammable than the traditional palm thatch.[37] To make beams a little lighter yet a little stronger, they can be prestressed while prefabricating or posttensioning them. In Peru I found that the extra cost of using such beams (introduced in 1956) is about the same as that of using metal forms, but there is an extra saving in construction time, about one-fifth. Roughly half the Peruvian builders tried to use such beams whenever they were in a hurry, but architects did not like to restrict their imaginations to the available sizes. In Mexico, with its lower building wages, the beams were not used, and their use had not increased much in Peru by 1973.[38] Prestressing can mean a saving in fuel costs, since it saves cement, which is fuel intensive.

Zed Tiles and Tunnel Forms

Perhaps the most impressive ceiling component innovation by and for developing countries is the "Zed" or "Domoseta" tile from Pakistan. It is novel, capital and material saving, labor intensive, and simple. The tile consists of unreinforced doubly curved concrete, about 60 centimeters (to 30 inches) square and 2 centimeters (to one inch) thick. The strength-giving curvature is obtained simply by pouring the cement on hessian cloth or burlap stretched on a square wooden frame and letting it sag naturally with the wet weight. The tiles weigh 22.65 to 27.18 kilos and can be handled by one laborer. They are laid on the flanges of small ⊥ bars made of concrete that stretch from one wall to another. The tiles are set bulge upward, and to make a flat floor or roof, a concrete topping may be added. With a 10.16 centimeter topping of 1:4:8 concrete, the central breaking load was found to be 5,436 kilos.[39]

The Peruvian architect, Ernesto Paredes, who specified Zed tiles for his entry in the United Nations–sponsored PREVI competition in Lima in 1969, did not win, but his design proved to be the only one cheaper than conventional construction (by 12 percent). A group of architects using the French Outinord system won the PREVI competition with a design that was supposed to be 37 percent cheaper but proved to be 19 percent more expensive. The Outinord system is one of a family that uses a prefabricated *metal formwork in the shape of a* ∩ or "tunnel." Walls and ceilings are poured simultaneously. In multistory buildings one can begin a higher story before the lower one is completely set since the forms provide support. Capital is substituted for about one-third of the site workers, and construction time falls by half. Even so, the Outinord system is probably the most labor intensive of the modern European methods. The system was developed in France around 1952 and introduced in Latin America a decade later with varying results. In high income, high volume Puerto Rico, it was a success. Elsewhere, those who obtained the patent rights and had forms built were disappointed. One Colombian contractor who had acquired the system told me in 1970 that a 250-unit contract was sufficiently profitable for adoption. Three years later he told me that he was sorry he had become involved. He now felt 1,000 units — enough work to last four years — was the minimum. But the government seemed to consider it politically unwise to commit so much work to any one contractor. The equipment, once acquired, cannot be treated as a sunk cost, easy to use off and on. Assembling and training a crew, mobilizing a crane, and setting up a site are all very expensive. In addition, the forms need extensive repairs every year.

A contractor who has used the system successfully told me:

> If anything, the traditional system is just a tiny, tiny shade cheaper, but *Outinord* is so much faster. We put up a 20-story building in just 60 days, and I mean calendar days. Any traditional building that takes 100 days to put up, we put up in 30. Not only that, but we use only 30 percent as much labor. Only a few of the most skilled workers, crane operators and the like, are on our permanent payroll. And remember, no finish is needed with our system. That helps offset the fact that the cement we use is more expensive than bricks.
>
> Of course, the system depends on having a minimum volume. That's why so many of the other people have failed with their crazy schemes. I'd say 15,000 to 20,000 square meters is the minimum. At 100 square meters per unit that's 150 to 200 apartments. For smaller ones it has to be a minimum of 200 units. Actually, we're not really tempted until it

gets to 400 100-square-meter apartments. When the government asked us to build 64 small apartments, we refused.

It's not that we can't afford to have our equipment idle. What is critical is moving all the material to the site, especially the crane, and then not having it fully occupied. The system is definitely impossible for individual houses because of this. About half the time, we use the traditional system. In addition to *Outinord*, we use prefabricated beams, not just for supports of the ceiling, but for the structure itself. This very building [we are in] is an example.

Natural Rubber-Bagasse Roofing Sheets

After three and one-half years of research investigating the possibilities of less expensive roofing materials in Jamaica, the Philippines, and Ghana, a way of making roofing sheets out of bagasse and natural rubber was developed. Financial support came in part from the U.S. Agency for International Development, and the research was carried out by the Monsanto Research Corporation together with the Building and Road Research Institute in Ghana and similar organizations in the other countries. Chemical additives had to be found to improve the structural and environmental traits of the sheets. Prototype housing was expected to be finished in the Sekondi-Takoradi area of Ghana during 1978. Costs per sheet were expected to be between one-third and one-half of those for competing roofing materials, such as tiles. Since both rubber and bagasse are available locally, the import content will be low.

The Newfangled and Bizarre

Despite popular distaste for freakish roofs, designers continue to devise grotesque geometrical shapes using unheard-of materials. In Mexico, houses with prestressed domes could be rented but not sold. Some architects felt that a design was not truly forward looking until it could be neither rented, nor sold, nor even given away. A surprising fact is that not all nominally cost-reducing roofing innovations are flamboyant extravaganzas (like the Sydney Opera), and that some are even practical.

In 1955 on a Kenyan tea estate, J.F. Will started building *concrete rondavel houses.* With a special set of forms, the 3-inch thick circular walls and domed roof were cast in a single day. The forms cost US$3,000. It took one day to set them up, and six or seven days for the cement to harden. Annually, some 46 houses could be made per form.

The company hoped to build 5,000 houses at a cost of about US$240, roughly half that of a traditional African hut. All those pillboxes must have looked something like the Maginot Line. Their thermal characteristics were not recorded.[40]

As a cheap substitute for the metal forms, some architects have suggested using *balloons*. Blow them up, spray on cement, let it harden, and collapse the balloon for use elsewhere. An Israeli architect, Haim Heifetz, patented one system and used it to build hundreds of dwellings, especially in the Sinai desert. Cost per square foot (shell only) for six to ten units was US$3.10 for 33-foot diameters and US$6.35 for 99-foot diameters. Except for the balloon, the system is not unlike the ferrocement discussed in the previous section.[41]

A widely used innovation for roofs is the long interlocking N-shaped asbestos cement channel, invented by Alvaro Ortega of the United Nations and called *canaletas* or *canalones*. No supports are needed since a single piece goes from wall to wall. A disadvantage is that this ceiling cannot also serve as a floor for a higher story. Price is uncertain since asbestos cement products often are made by a monopoly that can vary its price up or down by 50 percent. The channels can be shipped in a compact stacked way. Installation is merely a matter of setting them in place.

The CBRI and the Indian Forest Research Institute, Dehra Dun, have developed coconut particle roofing boards to a point of having potential. An advantage is that only 0.5 percent resin adhesive need be used, compared with 6.10 percent in other particle boards, a major cost reduction. And fire retardant treatment is not needed. When a coconut board catches fire, it will helpfully extinguish itself. Of course, a suitable coconut chipping machine had to be developed.[42]

We have discussed the use of such familiar materials as concrete in strange shapes like balloon shells and the use of such strange materials as coconuts in the familiar shape of boards. What remains to be treated are strange materials in strange shapes, in other words, *plastics*. The most marvelous and fantastic experiments of all were sponsored by the U.S. Agency for International Development in the mid-1960s and carried out at the University of Michigan, Ann Arbor, in collaboration with the Dow Chemical Company, the Union Carbide Corporation, and the Wyandotte Chemicals Corporation. A special spiral-generating machine and two workers bent, placed, and fastened strips of polystyrene foam, layer upon layer, to make a 13.72 meter dome in less than 12 hours. They then cut out the windows and door and poured a cement slab.

In another experiment, a two-story test structure was made out of polyurethane foam boards with a triangulated bent and held together with polyester impregnated fiberglass tape. One polyurethane structure was sprayed against a folding lattice armature covered with nylon-reinforced paper. Still another consisted of rigidized flexible foam sprayed with chopped glass fibers and polyester resin and fastened on top of tubular columns. The technicians in charge believed that any preliminary cost figures would only be misleading and meaningless; nevertheless, "these experiments have shown foam plastic structures to be within the realm of technical and economic feasibility."[43] Another idea was winding the housing shell with a glass filament.

As far as I know, no less developed country has ever built such houses. Even though building codes might be moot as to whether or not they could be built, there is something of a customer risk. One circular house was built in Traverse City, Michigan, and the U.S. Army put up quite a few plastic shelters in the Arctic. That was about it. Some types might have been a fire hazard, and others had a tendency to melt under intense heat and give off dense smoke and poisonous fumes. A Canadian expert concluded that "the inherent properties of plastics suggest that by themselves they cannot form ideal house structures, now or for some time to come."[44] The best bet for Canada was to bond plastics with wood fiber to make boards. The British Building Research Station agreed: "What are called 'all plastics houses for developing countries' claim advantages many of which seem to be very questionable. . . . They suffer from lack of thermal capacity and high cost. . . . For normal everyday uses, complete buildings in plastics are likely to remain in the realm of fantasy."[45]

A word is in order about risk and plastic materials. One risk is that of "interference" by competitors who spread rumors about fast deterioration and lack of safety. Where materials have been carefully tested, as in the University of Michigan and Washington University, St. Louis, Missouri, projects, information exists for contradicting these rumors. The spread of plastics nevertheless calls for stress on the combustibility and doubtful weathering ability of carbon-based plastics. The high intensity of ultraviolet radiation and high temperatures in the tropics accelerate degradation, while intense rainstorms wash away the results, exposing a fresh surface to the sun. The British Building Research Station estimates that degradation proceeds at about three times the rate of temperate regions, depending on additives and other factors. The Swiss Reinsurance Company of Zurich calls polyurethane, polystyrene, and polyethylene especially hazardous and says that fire retardant additives are effective only to a "slight degree." It warns carriers of the need to use extreme caution in insuring buildings using large quantities of plastics.[46]

In the United States the Federal Trade Commission charged 26 chemical companies with misrepresenting the fire hazard from urethane foam.[47] But more persuasive than these warnings and charges is probably the fire that killed 189 persons in a 22-story building in São Paulo, Brazil, in February 1974. Plastics in paint, window frames, and floor coverings helped spread the fire. The deaths were partly due to the lack of interior fire stairs and exterior fire escapes which had been in the plans but were, in fact, not built. Four central core elevators jammed, cremating the occupants.

Plastics can serve well as flooring, insulation, and pipes, and all these uses will be discussed later. Here we shall conclude with the *bamboo-polyurethane beam* of Peru and the *foam matrix roofing system* of Washington University, St. Louis. The beams were developed by Christopher Alexander of the Centre for Environmental Structure for the United Nations PREVI program. The beams are made of six-centimeter bamboo rods placed over plywood templates, with a core of two-pound density polyurethane fire retardant foam, sprayed in place. They are 20 × 40 centimeters wide and 5 meters long. They cost half as much as a comparable reinforced concrete beam and weigh only 40 percent as much. They can be cut with simple tools and handled by two men. If the foam is available cheaply, they economize on all inputs but must still be considered a proposal with no more than potential.

The same goes for the low-density foam matrix reinforced with local reinforcing fibers developed by the Center for Development Technology of Washington University. These are undergoing field trials in three climatic zones of Mexico. The center is also exploring possibilities for raising efficiency of wooden housing in developing countries, specifically Ghana.[48]

4

Innovations in Finishing, Materials, Sitework, and Housing Design

In this chapter, confusing as it may sound, we begin with finishing. Once the shell of a house is up, the dwelling is "finished" by putting in floors, doors, windows, fixtures, plumbing, painting, and the like. Expenditures on these items more than anything else determine whether a dwelling of a given size will be low or high cost. In low cost Puerto Rican housing, finishing constitutes about two-thirds the cost of the unfinished shell, that is, about 40 percent of the total (without land). In some efficiently built British row houses, finishing and utilities amount to 71 percent of the total.

Floors

The chapter on the shell began with the foundations; hence, this one appropriately begins with floors. A difference is that floors, unlike foundations, can be omitted. Poor people can set a straw mat on dirt, or they can paint a slab of cement. In Brazil, much low cost housing is built with parquet floors that would arouse the envy of homeowners around the North Atlantic. Where wood and labor are cheap, the choice is no floor or luxury parquet. Marble and ceramic floor tiles are better tropical possibilities.

An intermediate technological solution was developed in Colombia as early as 1956: the *cement floor tile.* The Inter-American Housing Center (CINVA) in Bogota designed a simple pressing machine operated by three workers, using cheap wooden molds, and producing 500 tiles daily. This technology later diffused to Mexico. Considering that terrazzo floor tiles had long been used there, this flooring innovation was hardly earthshaking. In Mexico, tile-making machinery was developed as early as 1931. Since such tiles and machinery were not used in the United States, competition from abroad was no problem. Bits of marble are dropped into the cement matrix, and the tile is then cooked and polished. Some French and Italian firms later made the mixing, grinding, pressing, cooking, and polishing a continuous automated process.[1]

In India around 1967 the CBRI developed a science-dependent innovation for making *terrazzo tiles* cheaper. Instead of using magnesite based cement, a way of making *magnesium oxychloride* from low grade dolomite was found. Cost reduction was reported to be 30 percent, and the process is being licensed commercially.[2]

A more capital- and materials-intensive way of making terrazzo floors is to pour a whole layer of marble and cement in part of a building, let that layer dry, and polish it. In Caracas, floor costs were halved by not putting the marble aggregate in a thin top layer, but by using aggregate throughout a slab and polishing that, eliminating separate layers. This was called *integral terrazzo.* By spending more on marble and less on labor, flooring costs were halved. Wherever construction wages rose sufficiently, this off-shelf innovation followed.

Of all flooring innovations, *vinyl tiles* have been the most popular. In Peru, for example, they were introduced in 1959 by a company that was already making asbestos tiles. Material costs were about two-thirds that of competing parquet floors; per square meter of floor, fifty minutes of labor were saved. All firms in a sample had adopted this innovation, most within two years. The tiles became standard in all but the lowest cost housing. By contrast, in India the price of vinyl tiles remained four or five times above the world market price, and the product was little used except in prestige buildings.[3] In Rio de Janeiro in the mid-1970s, vinyl tiles also remained more expensive than peroba wood parquet floors.

Utilities and Fixtures

As with every other dwelling component, the cost of utilities and fixtures can be lowered by changing their design, materials, or method of installation. Many options lower quality more than cost and are not really innovations. Much useful work can be done in standardizing doors, windows, closets, kitchen components, and bathroom fixtures. To be successful, such work calls for joint meetings of manufacturers, architects, and developers so that components will be made to fit a variety of designs and yet meet industrial capacity and constraints. Some joint efforts of this type are currently under way in Mexico. Unfortunately, most designers do not find this type of effort as exciting as devising new approaches to plumbing, electricity, or heating, known as the "water-waste system" or the "energy system." Perhaps more attention for other fixtures could be achieved by referring to "entrance-exit systems" and "window modules."

Basically, of course, plumbing is as important to human life as water itself. In poor countries, the water supply promotes both life and death since it is the main source of disease. Human settlements rank first as environmental polluters because of their effect on water; hence, successful urbanization is more a matter of putting in pipes than of laying out streets. When water is pumped into dwellings, its use per person quintuples, and so does the need for drainage.

The most common plumbing innovation in developing countries is the substitution of one material for another in pipes, an off-shelf change with a substantial saving in materials cost and a moderate amount of customer risk. The traditional materials until the mid-1950s were galvanized or cast iron pipes. In many countries, galvanized pipes were expensive imports, and cast iron pipes, although about one-third as expensive, corroded rapidly (sometimes in two or three years). In the mid-1950s *asbestos cement pipes* began to be used for internal plumbing in some countries, especially when their price was about half that of cast iron (with no rusting to be expected). But asbestos pipes quickly encountered new competition: *PVC pipes.*

Electrical insulation in the form of 1.27 centimeter tubes was the first use of PVC (polyvinylchloride), beginning in Latin America around 1953. Their use for water and other liquids began two or three years later with industrial plants and with water supply systems in barely accessible sites. In 1968 the Peruvian list price of PVC pipes (3.81 centimeter, 7.35 kilos pressure) was 3 percent below that of asbestos cement pipes, and the innovation spread more rapidly than any other. Since 1964 these pipes have been specified in Peruvian government housing projects. Meanwhile, their use had not yet spread to Mexico, India, and other countries for dwellings, and 63 percent of U.S. building codes actually prohibited them.

According to rumors, the PVC poisoned water but was very nutritious for rats. An interference risk came from competing plumbers, who spread such rumors and opposed building code changes. After all, PVC pipes needed no paint and easily could be sawed, tapered, and glued together with a plastic solvent, creating much less work per dwelling than galvanized iron or copper pipes. In Peru, two-thirds of sample firms had accepted PVC pipes, but with a comparatively long average delay of 4.6 years.[4]

If PVC pipes are superior, why not use PVC in toilets and other fixtures? For a time the French Centre Scientifique et Technique du Batiment cooperated with chemical firms in designing the *optimal plastic toilet* for developing countries. In Mexico, the Instituto Nacional de Vivienda designed an entire plastic shower–toilet–kitchen sink module to be attached to houses lacking such facilities. A brochure about it was produced and distributed, but not the units themselves. In the Philippines, the Agency for International Development financed *quadruple plumbing* cores with four toilets back to back. These were to be rented to tenants who were to build a house with one toilet corner as point of departure. Having a rented back-to-back toilet was inconsistent with traditional Philippine homeownership values and failed to beget the expected response. The project was a victim of excessive customer risk and, according to Charles Abrams, came to be known as "Flushing Heights."[5]

An even more advanced cost-reducing innovation would eliminate municipal water and sewer pipes altogether. Rainwater would be collected, used, and *recycled.* Human waste and garbage would not go to a septic tank, but into a digestor where bacteria would break it down into methane, which could be used for cooking. Heat from warm, soapy water could help this process along before the soapy water would be sand-filtered, neutralized, and recycled. The water would have been warmed in the first place by a solar heater.[6]

A number of interesting design innovations were generated by the 1970 competition, "Housing in Developing Countries," held in Denmark. To keep the solution within the economic means of most families, it was specified the design be limited to the elementary needs of protection against the weather, safety during sleep, and hygiene. Professionally assembled frameworks with informally filled-in walls were expected to be a convincing solution, but they were disappointing because the implied industrialized production was too expensive. Several designs using arched roofs — curved metal sheets, arched blocks, and cement on hessian and wire netting — were seen as more promising. But the first prize was awarded unanimously to a sites and services proposal that stressed not low cost housing, but low cost urbanization. A central element was a waste disposal system consisting of a sort of bog in line with a Swedish innovation of around 1940, called "multrummet."[7]

According to D. J. Dwyer, no water-borne sewerage system is likely to be within the means of developing countries. Instead, excreta would fall into simple concrete boxes that are periodically emptied by special hand-operated cesspit emptiers into wagons or trucks. Presumably, running the trucks is cheaper than installing pipes and pumping water. Dar es Salaam has tried the system with ten vacuum trucks, but at one time seven were out of commission due to a lack of spare parts.[8]

Among all these ideas, *solar water heaters* stand out as already technologically and commercially successful. They are in use in Greece, Cyprus, Israel, South Africa, Japan, and the United States and typically cost US$150 to $200. They consist, first, of an absorber for solar radiation, perhaps blackened corrugated metal covered with glass. Water is heated as it drips down along the sunny grooves on its way to an insulated storage tank. The South African Building Research Institute has tested ten designs to determine how efficiency varies with different materials and sizes of storage tank. One of the most efficient is a low cost unit (US$25 in 1971) with a 37.85-liter capacity. On sunny days it provides enough hot water for a family of four adults and three children. The solar water heater is a science-dependent innovation that saves equipment, materials, and especially fuel or electricity while reducing atmospheric pollution. Some face customer risks as being an unsightly addition to the roof, but, like television antennae, it should be possible to overcome that hurdle. A group of Cambridge architects has thought in terms of a 37,850-liter underground tank with water heated to 50 degrees centigrade by recirculation. That much water would not be needed by the average family during the average day, but it could help to heat the entire house — a superfluous idea from the tropical point of view.[9]

Other Materials Innovations

This section is something of a grab bag of miscellaneous leftovers which hence might be thought unimportant. Miscellaneous, yes; unimportant, no. Since buildings, apart from tents and trailers, are not expected to be mobile (and are even called *biens immobiliers* with French precision), they can be materials intensive in the physical sense. Any locally available material that gives strength through bulk, especially if cheap, is a possibility.

Most less developed countries lack forests comparable to the vast homogeneous coniferous stands of the subarctic latitudes, but being warm and humid, they do not lack the termite. Hence lumber is a common building material primarily in North America, Scandinavia, and the Soviet Union. Many of the innovations already surveyed economize on steel, cement, glass, aluminum, and even bricks — all capital and energy intensive — which are more suitable to the resource endowment and trading capacity of industrialized nations. In a few countries materials are altered to economize on scarce skills or even to make self-help construction possible. Materials changes are important in cost-reducing innovations in many industries, but in building they are central.

The few illustrative innovations that will be catalogued here mainly promote the use of some local material other than stone, which is inconveniently heavy. Merely to list the materials conjures up the diverse landscapes below the Tropic of Cancer: rice husks, cashew nuts, sisal, palms, bamboo.

Some traditional materials are combined with modern ones to make variations of concrete. In Egypt, chemically treated *rice husks* have been used to make a very light concrete with excellent insulating qualities.[10] P. Kumar Mehta of the University of California has experimented with making a high silicone ash through the controlled burning of rice hulls. This ash combines readily with lime to form a fine black cement, as strong as Portland cement but more acid resistant. Mehta's process is said to require simple, small-scale equipment suitable for rural areas. Unlike conventional burning, pollution and consequent silicosis (a lung disease) will be less. Since the world harvests about 60 million tons of rice containing otherwise fairly useless hulls, these innovations deserve attention.

Another *ash cement* has been developed by the CBRI. This process produces aerated concrete from fly ash (a waste product from coal burned in power stations), lime, gypsum, and aluminum powder. Compared to ordinary cement, it reduces cost of materials by 40 percent and, being lighter, it can further reduce the cost of foundations.[11]

Any assertions about quality are statements about potential since proper mixing of excellent ingredients is a remaining step. Tests in Israel showed that costs, while still maintaining quality, could fall by 10–20 percent with *proper concrete weight batching* and precise water measuring techniques. The Israelis provided economic incentives to mixing crews through reorganizing their working methods, and they established a testing laboratory on the site. Twice the cost of the laboratory was saved. For identical amounts of cement, strength attained more than doubled. This innovation did not depend on science, inventions, or much investment: It shows the great potential of organizational improvements.[12]

The plague of termites in warm countries has been mentioned often enough in this volume. I do not wish to convey that man is impotent against the termite, or that he has a pacifist attitude toward rot, or that men are so busy fighting each other that they have no time to fight insects. If anything, that has been overdone with DDT. Against insects, defense is the best offense, meaning wood preservatives in the case of termites.

For example, a company in Cannanore, Kerala, India, is making a *wood preservative out of cashew nut shell extracts.* Even when bamboo is used as concrete reinforcement, the preservative reduces water absorption by 80 percent. Since two thick books are needed to explain all patents on cashew shell extract, one can see that much research has gone into the topic. The CBRI has even found the extract good for protecting polystyrene, if not against termites, at least against the weather.[13] Note that these science-dependent innovations save foreign exchange.

Meanwhile, in Malaysia, D. F. Densham-Booth developed the *dual-bath open-tank nonpressure system* of field impregnation of seasoned timber. He found that a cold soak alone, or a hot and cold soak in a single tank, were not as good as a two-hour hot soak followed by a two-hour cold plunge in a second tank. The double soak was almost as good as the more expensive vacuum pressure process. The tanks saved capital and foreign exchange by being of simple design and made of secondhand materials. They nevertheless allowed a three-man crew to process six tons of timber in eight hours. Densham-Booth believed, however, that weighing, mixing, and blending chemicals in Malaysia was more expensive than importing a ready-mixed, patented preservative from Yorkshire, called Tanalith.[14]

Importing a preservative may at times be advantageous, but more often the most economical materials are those at hand. Sisal and rock gypsum are both available in the Jordan valley, so combining the two scientifically for a better building material was a logical step. The Building Research Station of the Technion, Israel, took this step by developing *gypsum sisal facing boards.* The gypsum paste is mixed in a mobile tank with a retractable propeller. Sisal is added until the optimum 3 percent ratio is reached. For better strength a glass felt backing was found desirable. The boards are said to be potentially much cheaper than standard gypsum wallboard and suitable for low cost housing.

Not all building materials innovations require science and the adaptation of advanced technology. In New Guinea a helpful change has been the development of a *simple loom for weaving sago matting.* This matting uses the skin of the midrib of the sago palm frond. It has traditionally been woven by hand with considerable skill into blinds called selo, pungal, or sak-sak. Rate of output was one sheet (122 × 244 centimeters) per worker per day. In towns this product had trouble competing with hardboard ($0.78 per square meter), flat asbestos cement ($1.03), and galvanized iron ($1.01). Consequently, the Building Research Station, Department of Public Works, Port Moresby, developed a simple hand-operated loom that could be used by unskilled workers. Eight sheets could be produced daily per worker, and the cost per square meter of a double thickness fell to 64.5 cents. The matting's life expectancy was projected as 17 years. Local entrepreneurs have undertaken production on a cottage industry basis.[15]

Numerous other materials could be mentioned, together with their advantages and disadvantages. *Bamboo* is an example.[16] This ancient building material has an excellent strength-weight ratio, is easily worked with simple tools, no bark need be removed, and it is clean, hard, and attractive. At the same time, it is uneven, hard to standardize, easily split, and susceptible to rot, termites, and powderpost beetles. Some innovations using bamboo have already been mentioned, but many may never have been published in the technical literature. So it is with other materials. If a material is abundant, its building potential should be studied.

Sitework Procedures

Perhaps the best way to promote labor-intensive methods is to minimize their labor intensity. Capital-intensive processes are usually carefully engineered with all superfluous devices and operators omitted as the material moves from post to post in a steady flow. But in labor-intensive methods, workers have to move from task to task with many chances for interruptions, delays, and confusion. Disciplined coordination may be a joyless way of relating to one's fellows, but it is probably less degrading than unemployment or being a routinized component of an assembly line. Through the improvement of sitework procedures with more disciplined coordination, the labor intensity of much building work can be reduced and therefore some labor intensity preserved.

By labor-intensity we mean that of the product more than the process. In its detailed cost control study of conventional building methods, the UN-Peruvian Proyecto Experimental de Vivienda (PREVI) found that men and equipment are wasted about half the time. W. S. Forbes and others at the British Building Research Station (BRS) have come to a similar conclusion: Of the 1,200 man-hours per average dwelling, 600 consist of needless waiting, walking about, or other activities that fail to make the building grow. The British reached this conclusion by means of activity sampling. About 1,000 daily recordings at a building site are transcribed by an optical reader onto computer tape. The information processed deals with (1) the movement of the operatives around the site, (2) labor expenditure for each operation and dwelling, (3) the way time is expended per operation and by whom, and (4) the amount of unproductive time, when and why.[17]

With respect to bricklayers, the BRS concluded that there was no panacea for higher productivity, but

> unless correct work-sequencing and continuity of effort can be assured there is little hope that high output can be achieved. The bricklayers will be generally dissatisfied with the work, earnings will be low and valuable productive capacity will be underutilized. From the point of view of the individual craftsman, the studies have established that laying technique is a factor that affects productivity. Again, the principle involved seems to be based on the organization of work, so as to arrange the bricks and mortar at the workplace and to develop techniques to allow a continuous effort in "spreading mortar" — "laying bricks."[18]

That time studies and reorganization can lower cost in developing countries is supported by South African experience. Of the labor-materials cost of a brick dwelling, 38 percent was found to consist of labor, with two-thirds of the expenditure on skilled labor, but only 19 percent of the working time actually required skill. Careful study showed that highly skilled work was only 10 percent of the total and that better organization could lower the proportion of highly skilled brickworkers to the same 10 percent. For another 20 percent of tasks, workers with some on-site training and experience could be hired.

They could build up corners and work with a gauge. The remaining 70 percent of brickwork could be executed by workers without previous experience. As a result, 39 percent of labor costs could be saved, and overall labor cost would fall to 27 percent of the labor-materials total.[19] This successful but venerable organizational innovation may be called *task classification.*

As Adam Smith or any other student of pin factories knows, once labor has been subdivided and classified, *special tools* for special tasks can be invented. Following time and method studies such as those described above, the Indian CBRI developed special triangular trowels, L-shaped tools, and other gadgets that could be fabricated on the site as needed. In field studies, working height was changed, mortar spreading techniques were improved, and even better ways of stacking bricks proved helpful. As a result, the productivity of bricklayers rose by 30 percent. In a similar way, plastering productivity was raised 18 percent.[20]

Better sitework procedures should, therefore, not be thought of as purely organizational in all cases. In a tradition-ridden activity such as building, the most routine tools often can be improved. For example, nothing is more ordinary and ancient than scaffolding, the temporary structure around the permanent one. For five- and six-story buildings, probably nothing is cheaper than bamboo in the many countries where that plant grows. Since builders keep poor or no records of their scaffolding costs, one cannot say for sure. In Peru some builders preferred imported North American lumber because it lasted longer than local types, including eucalyptus. As early as 1951, however, a British firm began renting and selling tubular metal scaffolding, a capital-using, labor-saving change. For small buildings, erection time fell from half a day to half an hour. Virtually all firms in a small survey of contractors I conducted in 1968 had used metal scaffolding at one time or another. But the process need not stop there; metal scaffolding can be made still more labor saving. Bolts can be cast into the edges of floor slabs, and scaffolding brackets can be hooked to them. Not only labor but also steel is saved.[21]

Cost-Reducing Design Changes

To most architects a cost-reducing design change means to omit something previously specified or to make it of cheaper materials. Neither change is much of an innovation if the services provided by a dwelling fall in proportion (or more) to the saving, but the cost-reducing innovations introduced most easily are those that do not change the flow of housing services. Few customer risks are created by unseen changes in foundations, cement additives, reinforcements, brick materials, wood preservatives, pipes, formwork, scaffolding, or sitework procedures, that is, a good many of the innovations discussed thus far. If a change is visible, it is best that it involve the floor, as with vinyl tiles, which people notice only casually. Domed plastic roofs will be poorly received, even if substantially cheaper.

But just as there can be materials and sitework changes with unaltered designs, innovative designs need not involve bizarre skills, materials, or forms. The best architects can economize on construction work by ingenious fencing, roofing open spaces, improving circulation patterns, and so forth, by blending the scientific possibilities of familiar materials with the way people live in different cultures and climates. They can undo the damage of blind cross-cultural and cross-climatic copying. With luck, they may even approach the quality that preindustrial designs had for preindustrial life. Their worst dilemma arises when owners insist on copies of foreign styles, perhaps Tudor Bengal or Inca Gothic, no matter how uncomfortably wasteful.

An example of the creative directions in which design can move comes from Kerala, India. With the support of the government, an architect, L. W. Baker, has lowered costs by designing dwellings with unplastered loadbearing brick walls and by eliminating windows with brick latticework. For larger buildings these design changes are said to reduce costs by more than half, while the lowest cost houses provide 23.2 square meters at a cost of US$16 per square meter. This price includes a tile roof and a septic tank.[22]

The most obvious cost-saving design changes raise *density of occupation.* The German Institut für Bauforschung has tried to measure the effects of some changes, using a detached, two-story, two-dwelling house with a steep roof as point of departure. In terms of building costs, 2 percent is saved by switching to a flat roof, 6 percent per dwelling by making each a part of a row or terrace, and 8 percent with two dwellings per story. Constructing a three-story, six-family building saves another 12 percent. The total saving is 28 percent per dwelling compared with the original detached two-family house.[23] The German study failed to note that the savings are accompanied by a decline in services even if the physical specifications of the dwellings are unchanged. If people do not like climbing three flights and sharing a structure with several others (and under a flat roof at that), then they are receiving fewer housing services regardless of interior space and materials. To remain competitive with the original detached house, the apartments must provide more amenities per occupant, offering more space and higher quality, which reduces the relative saving.

Working closely with contractors and materials suppliers, the British Building Research Station (BRS) has shown the savings that can result from design changes in relatively conservative (timber-framed) dwelling types. A research and development group of the Department of the Environment was asked to design a housing scheme for 12.5 acres at a density of 60–70 persons per acre (148.14–172.83 persons per hectare). The resulting Finchampstead Project consisted of 172 dwellings for two- to six-person households. The BRS acted as consultant to designers and builders, using its activity sampling method to identify organizational problems and to devise better sequences, materials, and layouts. In their own words, the aims were:

> 1. To improve the quality of the finished houses without increasing costs by use of such techniques as delivery of components in house sets to avoid double handling and the complete enclosure of the house shell within a day to allow concentration of efforts and to keep materials dry.
> 2. To use largely externally finished components to reduce the number of site joints, and by use of factory finished components, such as door sets, staircases, kitchen fittings to provide a uniformly high standard of internal finish.
> 3. To develop a design that would allow as far as possible continuity of work for the different gangs, eliminate unnecessary work and reduce the labor content of the remaining work.[24]

Not many of the resulting design details can be mentioned here. The exterior cladding was 1.27 centimeter plywood sprayed with a water-based styrene acrylate-type resin containing glass aggregate, mica, and epoxy-coated granules. A delay of four weeks occurred when a need arose to respray these panels. At times they arrived on the site without windows installed as ordered. Internal plasterboard linings were fixed to the panels on the site.

Plumbing and electrical designs aimed to avoid trade-waiting-on-trade situations. An electrical box was devised that could be affixed directly to the plasterboard without the use of noggins. Since electricians were insufficiently skilled to cut proper holes in the plasterboard, a need arose to develop a simple device for cutting such holes accurately.

Another problem arose with plumbers. Annealed copper pipe was specified so that all the carcassing pipework could be done in one visit. The flexibility of the pipe was to allow its being "threaded" through holes in the predrilled joists. However, the appearance of such pipework offended the plumber's pride in his craft, and he insisted on using ordinary copper pipe, which entailed an extra visit to each house. Such attitudes, admirable but inefficient, characterize craftsmen throughout the world — an example is African carpenters who make cement formwork like fine furniture. Such craftsmen keep the labor-intensive approach too labor intensive.

The overall conclusion from the Finchampstead experience was as follows:

> Shell erection is no longer the most critical problem . . . . It would be quite practicable to build at the rate of two houses per day with the same size gang, i.e. five men and one crane . . . . The substructure and shell were successfully simplified. . . . The degree of prefabrication used was as much as was appropriate in the circumstances and possible with the cost information available.
>
> Design rationalization of plumbing, joinery, and finishes should be given priority. For example, it is essential to understand clearly at the design stage how the various sub-systems involved, for example kitchen fittings/ducts affect other sub-systems, such as plumbing runs/fittings and decoration. The components and materials forming each sub-system should be compatible in terms of degree of finish to avoid duplication of visits. . . . Using the information obtained from the site studies, further design rationalization should allow completion of the plumbing, joinery and finishes at a rate to match shell erection . . . to reduce the complexity of the work, simplify the efforts of site organization, and reduce the man-hour requirements.[25]

If it is worthwhile to rationalize and simplify rather conventional dwelling types in an industrialized country, would it not be more so in a developing country where labor is even cheaper and where traditional building remains more viable? Since the poor can only afford simple dwellings, how difficult is it to simplify them further? Where wages are pennies per day, are savings from labor displacement worth the expenditures on activity sampling and redesign efforts? Some answers to those questions might be: (1) The poorer a country is, the less it can afford to be inefficient; (2) until a dwelling has been simplified to a single component or two, such as an egg or snail shell, one cannot say *a priori* whether further simplification is self-reinforcing or subject to diminishing returns, and (3) better design can economize on inputs other than labor.

For example, at the College of Engineering of Madras, India, Velayudhan Raveendran and Madasamy Arockiasamy have estimated that a *cavity brick wall* will be 15 percent cheaper than a conventional one. The cavity walls would consist of bricks set on edge with a 4- to 5-centimeter air gap between. Corrosion-proof metal ties would join the two leaves of brick. Even in prolonged wet weather the inside face of the wall would remain dry. Lighter weight would reduce the dead load to the foundations. A 20-centimeter cavity wall, compared with a conventional 23-centimeter solid wall, would save 30 percent of the bricks and 30 percent of the mortar in cement, but require more labor for the net gain of only 15 percent, mentioned above. The cavity may advantageously conceal wiring and pipes, and disadvantageously provide some breeding space for vermin. For two-story buildings, using sufficiently strong bricks (100 kg/cm^2) and adequate lateral support, this design change would seem to be the prototype of an ideal for vermin-free developing countries.[26]

Sketchy Synopsis

The chapter began with finishing. Most flooring innovations were not earthshaking. An innovation whose diffusion has been only a trickle in rich countries but rapid in some poor ones is the PVC pipe. Solar water heaters are already a commercial success, but regretably they function best in torrid countries where they are not needed. Defense, in the form of wood preservatives, is the best offense against termites. Intermediate technology in New Guinea has raised productivity by a factor of eight in the manufacture of palm rib matting. As for sitework labor intensity, less of it, paradoxically, can raise employment. Statistical surveys have suggested that building workers spend half their working time not building. There is much walking about, trade-waiting-on-trade, and even pride in craftsmanship, admirable but perhaps inefficient.

Good design, nevertheless, means approaching the quality that preindustrial designs had for preindustrial life. Indian experience with the cavity brick wall supports the view that, given good design, an acceptable and rather cheap building material is air.

5

Cost Effects, Risks, Complexity, and Origins of Innovations

With little consideration for the ease of mind of readers, two chapters on cost-reducing building innovations have been presented without drawing any conclusions. If amends were not made now with some clear-cut or even fuzzy generalizations, how much could any reader retain from interminable details about one innovation after another? Most would remember that adaptations and experiments occur in a wide variety of countries with some, such as India, more active than others. Most would also be aware that all parts of dwellings have been innovationally assaulted — foundations, floors, walls, roofs, utilities, fixtures, and so forth. Perhaps a few would recall that walls and roofs have had the most attention and that, with respect to these, the making of blocks and bricks has been studied most intensively.

Perhaps readers will also recall that there have been both successes and failures, and a few bizarre cases may remain unforgotten, for example, the New Guinean sago matting loom. Some may have been surprised that solar water heaters are already a commercial success in many countries. Others may lament the murky record of plastics but rejoice at the success of PVC pipes. Pangs associated with lost dreams may eventually linger on with thoughts of unsuccessful industrialized systems building (ISB, discussed in chapter 6).

When it comes to employment, many readers may remain alarmed at the large number of labor-displacing suggestions. Some may console themselves with the memory of a few good labor-using ones, such as the Pakistani Zed tiles and the Mexican hyperbolic paraboloid shell foundations. Others may still be puzzling about the paradoxical experience of keeping labor-intensive methods viable by making organizational improvements that lower labor intensity. Beyond that, an impression may be widespread that science-dependent innovations lower the cost of materials.

Are such scraps of memory sufficient? Certainly not if more durable, more precise, and more general propositions can be distilled from all those cases, that is, if a welter of confused detail can be metamorphosed into a few simple and clear statements. Yet, simplicity is a kind of deceit if the real world of building experiments is, in fact, a confused welter. In this chapter of conclusions, we shall try to squeeze and distill as much simplicity out of confusion as is possible with the apparatus of assumptions and statistical hocus pocus. It will be a great advantage for our conclusions if they are substantially true; but if they are not, they should at least be clear enough so that they can be thoroughly discredited without much effort.

Analytical Categories

To evaluate a group of innovations, one must know their origins and their physical and economic characteristics. Were they developed by private, academic, or government technicians? Was their point of departure a scientific discovery, an advanced technique abroad, a local traditional building method, or an organizational problem? What physical part of the building was involved? Was the proposed change *simple,* involving only materials, only design, or only construction methods; or was it *complex,* involving two or all three of these? Were risks seen to be small or considerable? Was a minimum volume needed for success? On a per unit basis, for what inputs did costs rise or fall, and why? Did the output change in terms of quality, durability, maintainability, or some other characteristic? (The beginning of chapter 3 has already explored these issues in some detail.)

A problem is that not all reports on innovations examine all these questions. Most are thorough on physical specifications and vaguely overoptimistic on economic performance. Implications of variations in volume, relative input prices, and risks are seldom pursued. Unfortunately, I had neither the time nor the competence to divine the missing information for every building innovation that I came across. I must therefore resort to the assumption that those innovations which I heard about and for which most of the basic questions can be answered are representative of *all* building innovations. The number of innovations examined here is sixty-five (n = 65).

A second outrageous assumption is that answers can be classified sharply. For example, I use the categories *off-shelf, organizational, adapt-advanced, improve-traditional,* and *science-dependent. Off-shelf* changes simply mean the wider use of some well-known material or method from abroad. If it is a modern novelty from an industrialized country and requires engineering adaptations to local conditions, it becomes *adapt-advanced.* On the other hand, if an old local method is improved in a similar way, especially a rural technique for urban use, the classification is *improve-traditional.* If the adaptation or improvement calls for an investigation that takes problems back to their roots, then the innovation becomes *science-dependent.* New properties of materials and laws of behavior are formulated in these cases before design begins. *Organizational* changes raise productivity for given design with given materials and hardware. Obviously, some cases were blends of these categories, but none seemed exactly on the borderline, say, 50 percent improve-traditional and 50 percent adapt-advanced. To avoid further specious quantification, I simply put each case into one category or another. The results were as follows:

Cognitive characteristics of a sample of 65 building innovations

Type	*Number*	*Percentage*
Adapt-advanced	18	28
Off-shelf	17	26
Science-dependent	16	25
Improve-traditional	8	12
Organizational	6	9
Total	65	100

The typical innovation affected the shell or "structural envelope" of the dwelling and was *complex,* involving materials, design, and sitework (at least two) simultaneously. Most were labor saving and had considerable risk.

General Characteristics of
65 building innovations

Characteristics	*Number*	*Percentage*
Structural envelope change	41	63
Other changes	24	37
Complex	36	55
Simple	29	45
Considerable risk	37	57
Small risk	28	43
Total in each group	65	100

Yule's Q

Plainly, the next task is to relate these and other characteristics to one another. Since we have a set of discrete innovations that can be classified according to various criteria, the method of Yule's *Q* seems most appropriate. Yule's *Q* ranges from 1.0 (complete association) to −1.0 (complete disassociation) in relation to two characteristics that can each be present or absent. The null hypothesis is that the characteristics are independent.[1]

Labor Saving versus Material Saving

Since these chapters have stressed cost-reducing innovations above all, effects on costs should be considered first. Most striking is that innovations tend to reduce labor costs per dwelling, so that any expansion of employment had best be sought through exploiting demand elasticities and rises in volume. Science-dependent innovations do primarily lower material costs, but 77 percent of all other types of innovations have their primary cost-reducing effect on labor. According to a Yule's *Q* test, we can be more than 99 percent certain that this apparent association is not due to chance, although only part of the sample could be thus tested.

Proposition 1: Science-dependent innovations tend to reduce material costs, while others tend to reduce labor costs.

	Material cost down	Labor cost down
Science dependent	8	2
Off-shelf, adapt-advanced, improve-traditional, organizational	6	20
$Q = +.86$	$\chi^2 = 7.60$	$P < .01$

The association is somewhat more pronounced, rising from $Q = .86$ to $Q = .89$, if the least and most imaginative innovations are compared. These two extremes are the science-dependent and the off-shelf innovations. One requires thorough exploration and discovery, while the other is hardly more than copying (simple mechanization, hollow clay tiles, PVC pipes, and so forth). Of course, whenever a purely labor-displacing method comes off the shelf, a labor-using one goes back on, ready to be used when the ratio of wage to other prices changes. Note that the probability of the association being due to chance rises to between one and 2 percent ($P < .02$). This rise is due to the smaller number of cases.

Proposition 2: Science-dependent innovations tend to reduce material costs, while off-shelf innovations tend to reduce labor cost.

	Material cost down	Labor cost down
Science-dependent	8	2
Off-shelf	2	9
$Q = +.89$	$\chi^2 = 5.75$	$P < .02$

For both Propositions 1 and 2, innovations were excluded that reduced or increased *both* materials *and* labor cost. Hence, more can be said about the total sample. In the case of off-shelf innovations, 81 percent were labor saving. About one-third saved only skilled labor, one-third only unskilled labor, and one-third both skilled and unskilled labor. For half of the off-shelf changes, labor savings were the only cost reduction. About one-third raised and none lowered equipment costs. Effects on materials and foreign exchange costs were about evenly divided between rises and falls. The vast majority are a proven economic success.

By contrast, only a minority of the science-dependent innovations have already been proven economically successful. The literature (and its authors) tend to be vague about equipment, labor, and foreign exchange costs and are certain mainly that material costs will fall. This pattern is not surprising since materials are central to structural stability, durability, appearance, and so forth, and compel scientific analysis whenever something cheaper is to be tried in place of the more conventional.

Since the cheaper materials are likely to be locally abundant (avoiding transportation costs), Proposition 2 can be rephrased in order to bring that characteristic out directly. A subsample of 33 can be tested.

Proposition 3: Science-dependent innovations are likely to develop new uses of indigenous materials (or to fit local peculiarities, such as special foundation types), while off-shelf innovations are not.

	New use of indigenous materials	Indigenous materials not developed
Science-dependent	11	5
Off-shelf	0	17
$Q = +1.0$	$\chi^2 = 7.57$	$P < .01$

Since no off-shelf innovation from far away could very well yield a novel use of indigenous materials, it is not surprising that Yule's Q rises to a full 1.0. The subset includes all science-dependent and off-shelf innovations.

Rising Equipment Costs

Another characteristic that contrasts off-shelf and science-dependent innovations is the effect on equipment costs. In construction, it is often useful to distinguish these costs from capital costs in general. Most of the capital invested by building enterprises is likely to be in the form of materials inventories and unfinished structures while the work is in progress. Equipment may be only a small part of the capital involved and therefore has to be considered separately in order to stand out.

Off-shelf innovations are far more likely to raise equipment costs, it appears, than are science-dependent ones. The innovation itself may actually consist of no more than bringing in such equipment for local use. Another category, adapt-advanced, is also more likely to be equipment intensive, while innovations that are organizational or that improve traditional methods are unlikely to raise such costs. We have, therefore, tested the following:

Proposition 4: Off-shelf innovations and innovations adapting advanced technology are likely to increase equipment cost, while other innovation types are not.

	Equipment cost up	Equipment cost not up
Off-shelf and adapt-advanced	14	19
Organizational, improve-traditional, and science-dependent	4	24
$Q = +.63$	$\chi^2 = 4.50$	$P < .05$

Equipment costs rise only in a minority of all cases, but for off-shelf and adapt-advanced, that minority is large.

An interesting difference between off-shelf and adapt-advanced innovations is that about 90 percent of the latter apply to the shell or structural envelope, compared with less than half for off-shelf. Both types share strong labor-saving tendencies. This effect is clear in two-thirds of the adapt-advanced innovations and indeterminate for the remaining one-third. There seems to be a 50 percent greater tendency to save skilled than unskilled labor. The effect on materials and foreign exchange costs is indeterminate, with about as many rises as falls. However, no adapt-advanced cases of falling equipment costs were found.

None of these characteristics are very surprising if one recalls that conspicuous among innovations classified as adapt-advanced are various processes for making and using blocks, tiles, beams, prefabricated forms, and especially panels. These innovations could rarely be introduced in an off-shelf fashion, that is, without some adaptations to local materials and income levels. But since they are equipment using and labor saving, it is often impossible to adapt them sufficiently to succeed in their basic aim, cost reduction. Even when they are helped along uneconomically by underpriced capital and overpriced labor, the most extreme industrialized panel systems have repeatedly failed in poor countries because of insufficient volume. Depending on the system, the annual minimum is 200 to 1,000 dwelling units at one site and enough business for three to five years. Wishful thinking about the ability to sustain volumes is an endearing but mischievous bias of systems promoters.

Risk and Complexity

The adapt-advanced innovations not only are riskier because they are equipment intensive, inconsistent with factor scarcities, and dependent on high volume, but also are likely to be the most complex, involving simultaneous novelties in design, materials, and construction methods. A Yule's *Q* test of the entire sample implies that such boldness has a .62 association with higher risks at a probability of better than 98 percent.

Proposition 5: Simple innovations that change only design, only materials, or only methods have small risk, while complex innovations have considerable risk.

	Simple	Complex
Small risk	18	10
Considerable risk	11	26
$Q = +.62$	$\chi^2 = 6.37$	$P < .02$

Among simple innovations, 62 percent had small risk, whereas 70 percent of complex innovations had considerable risk. Two-thirds of the adapt-advanced innovations were complex. Less than half of the science-dependent and organizational ones were complex, as were about 60 percent of off-shelf and improve-traditional.

Although 56 percent of science-dependent innovations were simple and 59 percent of all others were not, one cannot confidently conclude that an association exists, as stated by the following proposition:

Proposition 6: Science-dependent innovations tend to be simple, while others tend to be complex.

	Simple	Complex
Science-dependent	9	7
All others	20	29
$Q = +.44$	$\chi^2 = .62$	$P > .30$

There is a chance of over 30 percent that the association is accidental. If organizational innovations are grouped with the science-dependent ones, the degree of association changes little, but the probability of its being accidental falls below 20 percent.

Proposition 7: Science-dependent and organizational innovations tend to be simple, while off-shelf, adapt-advanced, and improve-traditional tend to be complex.

	Simple	Complex
Science-dependent and organizational	13	9
Off-shelf, adapt-advanced, and improve-traditional	16	27
$Q = +.42$	$\chi^2 = 2.00$	$P < .20$

The adapt-advanced category, however, was risky because it was equipment intensive and complex, not because it simply happened to involve the structural envelope or shell more than any other part of the house. The slight association ($Q = +.34$) between complexity and structural envelope changes had a more than 30 percent chance of being accidental.

Apart from indications of riskiness and complexity, almost no information on the cost of the innovating process itself is available. Our level of analysis is therefore much cruder than a comprehensive account of the cost-effectiveness of search. Extracting such information from research institutes and builders seemed virtually impossible, hence itself not very cost effective.

Origins and False Implications

Despite all these Yule's Q tests, we are not yet prepared to say that some innovation types are good and others are bad just because some appear less labor saving, less equipment using, and more creative with local materials. If that were so, the best policy would be simply to order more of good innovation types and to forbid others. Since the undiscovered cannot be specified from a catalogue, one would actually have to shift support to those who generally have tried to develop and introduce the good instead of the bad things. Science-dependent, improve-traditional, and organizational innovations would seem to qualify as good; since these typically have been introduced by public agencies, such bodies should therefore have more support. Unimaginative off-shelf changes, by contrast, are associated with private firms, and for such misdeeds they should be whacked on the knuckles. Yule's Q clearly indicts and absolves these goats and sheep . . . or does it?

Proposition 8: Science-dependent, improve-traditional, and organizational innovations tend to be associated with public agencies, while off-shelf innovations are associated with private firms.

	Public	Private
Science-dependent, improve-traditional, and organizational	23	3
Off-shelf	1	16
$Q = +.98$	$\chi^2 = 25.17$	$P < .001$

Before signing checks or arrest warrants, one might ask: What sorts of science-dependent and other innovations are the public agencies introducing? Are they economically most beneficial, associated with little risk, hence simple? Here the oracular Yule's Q is inconclusive.

Proposition 9: Simple innovations tend to be associated with public agencies, while complex innovations tend to be associated with private firms.

	Public	Private
Simple	16	7
Complex	15	14
$Q = +.36$	$\chi^2 = 1.04$	$P > .30$

The association stated by Proposition 9 cannot be accepted because that sample includes the complex, risky, equipment-using adapt-advanced innovations. These have been promoted more by public agencies than private firms by a ratio of about 3:2. Public agencies have been especially tempted by the lure of industrialized systems building. With the promoters' ability to influence the government budget and credit institutions, such "low cost" housing projects, although economically inferior, were not always a financial disaster. In extreme, yet rather common circumstances, the dwellings could be rented or sold to the upper middle class. Basically, however, they were a waste.

What sort of innovator should be tolerated or supported does not depend on what sort of innovations he favors but on the probability of waste. Whether or not an expenditure is recognized as a waste depends on how its repercussions are measured. Are actual but distorted (non-competitive) prices used? Or are capital and labor appraised in terms of their general value (productivity) throughout the economy? Are indirect effects on sanitation, health, congestion, thrift, and even social harmony included? In other words, the technicalities of equilibrium pricing and externalities could be raised.

Information about our sample of innovations, which comes from personal interviews, correspondence, and a search of the literature, does not allow such sophisticated evaluation. Concerning most of the "good" science-dependent and improve-traditional innovations, we only know that they were a *technical* success to some extent, or no one would have mentioned them. On balance, they seemed to be stressing use of cheap local materials instead of substituting equipment for labor. But that is not to say they were a proven *economic* success. Most of the science-dependent innovations can be rated no higher than as having economic potential. Only one of the improve-traditional innovations — the New Guinea sago matting loom — was a proven economic success in poor countries. Even the chances of asphalt-stabilized adobe bricks must be regarded as uncertain as the future price of petroleum. By contrast, over 80 percent of the off-shelf innovations have been economically successful and are diffusing gradually through one economy after another. Among the failures are some government-sponsored "housing factories" that were so unimaginative that they cannot even be classified as adapt-advanced.

Although public agencies do not often take enough initiative about off-shelf innovations to be classified as the innovators, public research institutes do help to spread them by giving advice and mentioning them in technical bulletins. More sophisticated professional journals rarely mention off-shelf changes, no doubt because they are not very challenging or stimulating intellectually. Anything that does not seem improbable is dull to read about. In addition, off-shelf changes, being well established abroad, often do not need local testing by public research institutes and subsequent promulgation with great flourish. On the contrary, if they are well established, it is embarrassing to have stumbled across them so late.

About one-third of the off-shelf changes were introduced by branches of international corporations, usually materials or equipment suppliers. In most other cases the introduction was made by employees who were knowledgeable about foreign products and were experienced because of training and travel. Although most of these changes were labor saving, only a few depended on a large volume of use in the sense of many dwellings at a single site. Interference with off-shelf innovating, or even with advertising what the shelf has, would seem to encourage, not retard, waste. The need is to make architects, engineers, and contractors better judges of all (correctly priced) options.

The view that off-shelf innovations are neither bad *per se* nor an exclusive concern of the private sector is also held by others. A.D. Daldy and R. Sperling of the British Building Research Station listed off-shelf dissemination as one of the highest priorities for building research institutes in developing countries. Others are development of local materials, promotion of organizational changes for greater site efficiency, encouragement of designs that avoid waste of materials, and low cost housing suitable for local customs and climate. Their view of science-dependent innovating appears skeptical:

> Basic research is clearly of greatest importance to mankind; however it rarely produces rapid results and it can be directed only by highly-qualified scientists .... Thus it is preferable for a new building research station to concentrate on the other (stated above) activities for the first years of its existence. Another reason for the postponement is that the director has to produce results during the first years in order to demonstrate clearly that the money being spent on the station is being well invested: thus he must concentrate on subjects of immediate importance.[2]

The choice from among different general types of innovation is, therefore, not an easy one, with two exceptions. First, it is always wise to beware of physical panaceas for the entire housing shortage. These equipment-intensive, volume-demanding schemes reappear each decade under a new name: "prefabrication," "industrialization," "modular coordination," "systems building." Although they are suitable for some components of dwellings, they are not generally appropriate technology for poorer or even all wealthier nations, as will be shown in chapter 6. They have a general place only during a temporary phase at the middle income level, especially in giant urbanized areas. Elsewhere, they only seem to be appropriate because decision makers in the building industry lack "appropriate education."

What is lacking is an understanding of the economics of efficient labor-intensive flexibility. If this understanding were there, organizational innovations would surely not be our smallest category. Failure with an organizational innovation appears very unlikely. Some of these were discussed on pages 78–80. One was "task classification" for more efficient use of skilled brickworkers in South Africa. With a principal investment in a few time studies, building costs could be reduced by 15 percent. The British Finchampstead activity sampling was a more elaborate version of this type of study. In Israel, setting up a field laboratory for controlling concrete quality when mixing at the site was a step that led to considerable savings and more than doubled the strength of cement. Some organizational changes are as minor as teaching workers to keep tool chests neatly arranged so that they do not waste time finding the proper tool or "make do" with an improper tool. Others involve larger issues of planning; for example, delayed completion of streets and service pipes can later interfere with the building process.

Reprise

Despite great hopes and lavish use of Yule's Q, sweeping generalizations and recommendations about innovations are not possible beyond pious support of good organization and warnings against large volume-dependent fixed investments. When the appropriateness of technology depends on volume, it partly depends on the appropriateness of policy toward demand or the channeling of mortgage finance. This policy will be more or less suitable, depending on the general perception of housing as an "appropriate sector," which in turn depends partly on the expected labor intensity of techniques. It is all very circular, or it would not be economics.

6

Industrialized Systems Building for Developing Countries: A Discouraging Prognosis

Architects, planners, and critics of urban affairs have often dreamed of one overall innovation that would subsume all others: industrialized systems building, or ISB. In some European countries this innovation has become a sometimes appealing, sometimes appalling, reality. This chapter explores its aptness for housing in developing countries. Analysis of the concept will show that it is no more than a partial answer to the production of housing, even in advanced nations. ISB implies high densities of settlement, and in few places is land so scarce that intermediate densities are ruled out.

Repeated failures and waste mark the record of ISB in most poor countries, as will be shown in a number of cases. Since cases taken out of context may not be convincing, mass production of housing is examined as part of the urban and economic trends in two Latin American countries, Colombia and Puerto Rico, in Appendices C and D. Colombians have long experimented with prefabrication and systems building, but only a few ideas have survived because of low Colombian man-hour costs, as little as US$0.40 in the early 1970s. In Puerto Rico, where hourly labor costs were high, US$2.60, systems building was almost competitive with conventional methods, but only in San Juan, where zoning authorities could enforce high-rise, high quality development. This chapter, therefore, has the task of deriving the recipe for failure, of explaining why in construction innovative rosebuds cannot rival cabbage.

The Concept

Scientists and engineers have widely replaced master craftsmen in the last two centuries under the motto: "The usual way of doing things is the wrong way." In the twentieth century the motto was compressed into a single word: "rationalization." To "rationalize" production means to study each facet of a commodity to determine whether it really serves a purpose and, if so, to see whether that purpose can be reached in a better, cheaper way. Rationalization not only strips away the blindly traditional as mere waste, but also combines some steps or components thought to be wholly distinct, while splitting others and examining substitutes for the very core of a process. Rationalization takes all means to a goal as variable and redefines goals themselves as multiple purpose means, probably inefficient until proven otherwise. Rationalization is the real mother of invention, while necessity is no more than a benign grandmother, contributing indirectly and unforeseeably from a distance.

In the case of housing or any other building, rationalization can be applied to the *design* of structures and to the urban plan by observing what goes on and arranging it in a better way. The *construction process* itself is a special and temporary activity on the site that can be rationalized by proper deployment of materials, equipment, and manpower, in space and over time. Everything should move along the shortest path, with no steps repeated. No slow phase should render workers and capital idle in potentially rapid phases: All should be synchronized along a "critical path." Economies should be sought through grouping repetitive actions, through simplification and standardization, through specialization in some cases and versatility in others, and through always calculating whether a machine or tool can pay for itself by lessening waste and man-hours of work. Production and design of *building materials* can be rationalized in the same way in the factory, forest, and mine.

Industrialized systems building, however, is more than the sum of rationalization at these separate stages. ISB is the simultaneous rationalization of all three — design, sitework, and materials production — in terms of one another: A group of dwellings is designed in a way that allows convenient site assembly of especially adapted but mass produced precision components.

Formally defined, industrialized systems building is the systematic and integrated application of mass production technology to construction and the manufacture of large building components. The large components are made under factory conditions of quality control, assembly-line processing, and tight cost management. The components are of standardized design suitable for quick, mechanical (dry) installation. Alternatively, they may be cast on the site with sophisticated multi-use forms set up mechanically and scientifically programmed. ISB may be applied to nonresidential or residential construction, to single family or multifamily units. It does not have a sharp boundary, but it definitely excludes conventional handicraft building methods, no matter how fully rationalized. When the prefabricated components of a load-bearing wall become light enough to be carried by one worker, the label ISB is no longer apt.

One thinks of load-bearing 10-ton panels with plumbing, wiring, and windows installed at the factory and perfectly painted, similar to the Puerto Rican Relbec system described in Appendix D. One also thinks of 100-ton modular boxes, typically half an apartment, such as Moshe Safdie's Habitat in Montreal or the unsuccessful Shelley Vivienda 70 in Puerto Rico. Implicit in all these schemes is that more rationalization is better than less, that complete rationalization means a comprehensive system of components, and that such a system had best be mass produced and assembled in an industrialized, capital-intensive way. The converse is usually set forth by ISB supporters, that unindustrialized building is backward, unsystematic, unpredictable, irrational, and extravagant.

Flaws in the Rationale for ISB

Support for industrialized systems building is usually based on claims that it is faster, cheaper, and better. This section will examine the validity of these claims, as well as other cost factors.

Quality

The claim that systems-built dwellings are of better quality is most easily disposed of. Presumably, higher quality is due to easier control at the factory than on the site. But the larger components must still be joined at the site, a task that becomes progressively more difficult. Higher quality within components frequently is offset by obvious patchwork on poor fits and by early cracks. Moreover, it is systems building itself that introduces precision quality demands that previously could be avoided. It raises quality in ways not sought by the occupants in order to prevent premature damage and deterioration in transport and handling. In design, more attention may be given to each detail when thousands of units are to be built, but if an error occurs, it is far more costly and awkward to correct once production is under way. Insofar as systems building compels high-rise apartment living, it clearly gives each consumer an inferior commodity. The external benefit of saving land and preserving the environment will be examined later.

Speed

The claim that ISB would solve the housing deficit of developing countries *faster* involves a logical confusion. The speed of assembling prefabricated components at a site gives few clues about the speed of launching an expanded housing program or about any raising of the annual rate of dwelling production. Under conditions prevailing in developing countries, traditional craftsmen and conventional building materials factories may take time to develop, but so does a smoothly functioning heavy panel system. In Puerto Rico, the Relbec-Larsen-Nielsen plant required two years for design and construction, although technological novelties were not intended.

Once construction enterprises exist, the annual volume of building depends less on a rapid rate of output from each enterprise than on their number, that is, on the volume of resources devoted to building. If housing is cheap enough, households will buy more of it, and unemployed workers can be recruited to make and place bricks and blocks. If dwellings are expensive and built with imported molds and cranes, one may encounter foreign exchange constraints, and a country may not be able to afford to build a large volume or to close the housing deficit fast, regardless of savings in months or hours per (more expensive) dwelling. Speed in removing housing shortages is an economic, not a physical, problem.

If speed of construction is converted to economic terms, other things being equal, the effect will be surprisingly small. Suppose a dwelling can be built in six months instead of a year without any other saving or expense. During the extra half year the slower dwelling will, on the average, be three-quarters finished. The cost of slower construction is the earnings forgone on this tied-up capital. If the interest rate is an annual 16 percent, that cost will be (.75 × .16/2) or only 6 percent of the value of the completed dwelling. To justify the six months' saving, no more than an additional 6 percent can be spent on ISB compared with conventional methods. It is assumed in this example that labor is not overpriced and capital underpriced, as so often is the case in poor countries.

Transport and Joining

The rational case for ISB, if any, hinges not on speed but on cost reduction, which, in turn, depends on high volume, consistency, and proper joints. Building components must be shaped, transported to the site, and lifted and fixed into place. The more shaping and fixing that is done in the factory, the cheaper a cluster of building components will probably be, for it is easier to perfect working conditions at a permanent indoor site. But the component will also be bigger, heavier, harder to transport, and more difficult to install at the site. Net cost reduction will occur only if these drawbacks do not outweigh factory economies.

Transporting heavy panels and modules is, in fact, much more difficult than transporting the sum of their parts and requires heavy trucks with A-frames for panels and big cranes at the factory and on the site. The proposed relatively modest Puerto Rican ARUV-Estiot system with its 4 × 5.5 meter panels would have required two 10-ton gantry cranes for the plant and the storage yard, each worth US$40,000 (in 1970). Tractors and trailers would cost $78,000; crane and rails on the site would cost $105,000. All these (except rails with a two-year life) would be amortized over five years. Setting the crane up at a site would cost an additional $6,000 twice a year.

Blocks, bricks, or concrete, by contrast, can be transported with much cheaper trucks and hoisting equipment. Damage during storage and transport is also less likely and less costly. During the first one or two years of an ISB system, a 20 percent damage rate is not unusual.

Even more serious, yet less widely appreciated, is the problem of making joints — locking, glueing, welding, hammering, or snapping building components together. With success or failure in this step, the building literally stands or falls. Larger components mean fewer joints, and it is this reduction that presumably speeds erection time. The saving will not occur if time per joint rises more than reduction in number of joints. Similarly, total cost of joining will not fall if the cost of each joint rises more than the reduction in their number. Is more or less fitting and trimming needed? In Puerto Rico, great problems arose with the posttensioning cables through the corners of the modular Shelley Boxes (see Appendix D). In another Latin American system, keeping supporting members level and avoiding gaps or overlaps with imprecisely fashioned three- to four-ton parts led to intractable joining problems, especially since the area was seismic.

Volume

The most crucial assumption, however, is about volume. Skill at transport and joining cannot overcome inadequacies in volume. Within a radius of about 50 kilometers of the component factory, over five years there must be a market for 1,000 to 8,000 almost identical dwelling units, depending on the type of ISB, or the investment will be wasted.

The dependence of industrialized housing on volume may again be illustrated with Puerto Rican data taken from Appendix D. Table 14 shows the breakdown of fixed costs (F) and variable costs (V) for the system of four-story buildings with six apartments per story. Since these buildings are designed to be built in pairs, the minimum annual volume of dwellings is 48. The maximum (and optimum) with the equipment specified is 300 per year, or 1,500 altogether. Only net costs are given, meaning that central office expenses and profits are not included. The fixed cost estimates assume two-year amortization for metal forms, panel storage supports, platforms, crane rails, and utility connections. Five-year amortization is assumed for cranes, vibrators, spreaders, compactors, screeders, finishers, sheds, warehouses, tractors, trailers, and a pick-up truck.

Table 15 shows what happens to total cost per unit (TUC) if only 48 instead of 300 units (n) are built. The fixed cost per dwelling unit ($TUC = F/n + V$) rises by over 500 percent, from $1,426 to $8,913. Total costs rise by 91 percent. The share of fixed costs in the total rises from 17.3 percent to 56.7 percent. These estimates in 1970 dollars assume prices of labor and capital at Puerto Rican levels, such as labor costs of $2.60 per hour. If labor costs are reduced to one-quarter (to $0.65) and finance costs are doubled, total cost per unit rises even more as volume falls: by 114 percent, from $7,785 to $16,655. The share of fixed costs rises from 21.3 percent to 62.7 percent.

For making the building shells, 30 workers were each to be equipped with $15,700 in capital equipment to make dwellings costing $109 per square meter. At an annual volume of 300 dwelling units, 50

Table 14. *Fixed and Variable Costs of Four-Story, Industrialized, Multifamily, 75-Square-Meter Housing Designed by the Planning Office, Puerto Rico Urban Renewal and Housing Administration*

Description	*Fixed cost, in U.S. dollars (maximum volume per year = 300)*	*Variable cost per dwelling, in U.S. dollars (minimum volume at a site = 48)*
Studies, plans, and fees	$147,750	—
Conventional construction of foundations	—	300
Materials	—	1,834
Prefabricating plant, amortization, utilities, and so forth	149,750	30
Transportation of panels, amortization, fuel, and so forth	16,600	28
Erection of buildings, amortization, electricity, and so forth	43;720	38
Labor for prefabrication, transportation, and erection of panels and general personnel expenses	—	1,029
Finishing work	—	3,364
Maintenance of dwellings during first year	—	100
Financing	70,000	88
Total	$427,820	$6,810

SOURCE: Computed from data in Planning Office, Puerto Rico Urban Renewal and Housing Administration, *Industrialized Housing Multi-storys–Puerto Rico* (San Juan: May 1972).

to 100 workers would be displaced, and among the remaining workers skill requirements would be much less.

After years of study that were heavily subsidized by a federal grant under Operation Breakthrough, the Puerto Rican government decided not to proceed with ARUV-Estiot. Demand would not be sufficient in coming years within a reasonable distance of any proposed plant. Moreover, labor displacement did not seem desirable when unemployment was above 10 percent and rising. Finally, costs remained too high for reaching those segments of the population that were ill-housed because of poverty. The Puerto Rican Department of Housing decided to use much cheaper light-weight asbestos cement panels imported from Colombia. In fall 1976, this system was about to be discontinued, as well, after building 1,200 rudimentary units at $84

Table 15. ***Fixed, Variable, and Total Cost per 75-Square-Meter Dwelling of Puerto Rican Industrialized Prototype Housing at Various Volumes of Output***

Cost	*Volume (number of dwelling units)* 300	192	96	48
Fixed cost, in U.S. dollars	1,426	2,228	4,456	8,913
Variable cost, in U.S. dollars	6,810	6,810	6,810	6,810
Total cost, in U.S. dollars	8,236	9,038	11,266	15,723
Cost per square meter, in U.S. dollars	109	120	150	209
Fixed cost as a percentage of total cost	17.3	24.7	39.6	56.7

SOURCE: Computed from data in Planning Office, Puerto Rico Urban Renewal and Housing Administration, *Industralized Housing Multi-storys–Puerto Rico* (San Juan: May 1972).

per square meter. Cement block makers claimed that they could do as well.

The Estiot-based, low volume system was still relatively labor intensive. At a volume of 300 units, the Relbec-Larsen-Nielsen system would have a fixed cost per dwelling of $21,333. This system with highly finished ten-ton panels (see Appendix D) involved a $6.4 million investment in a plant with a minimum annual volume of 1,500 units. Investment per worker was $51,200, compared with $15,700 per worker in the other Puerto Rican system. At a volume of only 48 units per year, the fixed cost per unit would rise to an absurd $133,333. Only with two-shift operation at 3,000 units per year would the fixed cost per unit of the Relbec system fall to a more reasonable $2,133. That volume of 3,000 units would have to be built for 5 years within a radius of 50 kilometers and still would not yield a reasonable cost for the typical income levels of developing countries. After all, these fixed costs do not include labor, fuel, or materials. The Relbec plant opened in 1972 and declared bankruptcy in 1976.

A final point about volume: While it is indispensable for ISB, it may be just as beneficial for traditional houses built in sets of several dozen. Such was the experience with the Paulo VI project in Bogota and with the British housing described below.

The Asymmetry of Cost Variations

The need for volume shows how fixed costs can push dwelling unit costs up if demand is insufficient. Even with adequate volume, delays and miscalculations can multiply expenses. A problem with an integrated operation is that when one thing stops, many other operations are also blocked. Many engineers prefer to think about prevention rather than alternatives and improvisations when things go wrong, and, optimistically, they prefer to lay out a "neat" physically complete system. In one country they rejected a design that would mean purchase of supplies from "a fragmented industry with many small establishments, which raises the possibility of encountering considerable difficulties in obtaining large quantities . . . for important construction projects." But with a "fragmented" industry, flexibility would surely be higher since not all plants would break down simultaneously. The difficulty is only psychological in not having a blueprint in advance of who will do what and how. It seems inefficient, but it works.

While costs can rise almost without limit, asymmetrically, ISB can lower them only marginally. ISB in annual volumes of 300 – 1,000 units does not normally cover foundations, installation of fixtures, and other finishing amounting to 60 – 70 percent of construction costs. It applies mainly to the erection of the shell — walls, floors, and the roof. Even without including costs of the site, taxes, insurance, and sales, the shell constitutes 30 – 40 percent of total construction costs. In a British-built low cost (US$6,700) single family house constructed in the late 1960s, the share of the shell was 41.7 percent.[1] In a US$9,500 Puerto Rican apartment in a four-story building, the share was 38.7 percent.[2] In a similar Colombian dwelling, the share was 28.6 percent. In Colombian single family and high-rise dwellings, conventionally built, the share of the shell was between 32 and 37 percent.[3]

In building the shell traditionally, the share of labor is between 30 and 40 percent. ISB normally saves labor and spends more on lighter weight, precision shaped materials. For example, in Polish, Russian, and Ukrainian large-panel building in the 1960s, man-hours per square or cubic meter were reported to be 35 percent less with large panel than with traditional construction. In these cases we may assume that the product is fairly homogeneous.[4] Now suppose that material costs do not rise at all and that labor is eliminated *entirely* in both the immediate prefabrication and site cost of the shell; even so, the saving as a share of the total dwelling construction cost will be very small. If labor costs are only one-third of shell costs, which are only one-third of total structural costs, saving *all* labor will only save one-ninth, or 11 percent. Not considering land, we may say conservatively that ISB cannot reduce structural costs by more than 10–15 percent, while it can easily double or triple them per unit if things go wrong.

If the cost of the site and sales costs are added, the proportion saved by ISB for the occupant can hardly reach even 10 percent with a complete set of optimistic assumptions unless the installation of windows, plumbing, and fixtures is added, but this means heavier, more complex components that further raise capital costs, volume requirements, and uncertainty. Any reported larger saving will probably be due to reductions in quality or to use of less land, not due to increases in efficiency.

The Role of Land Costs and Density

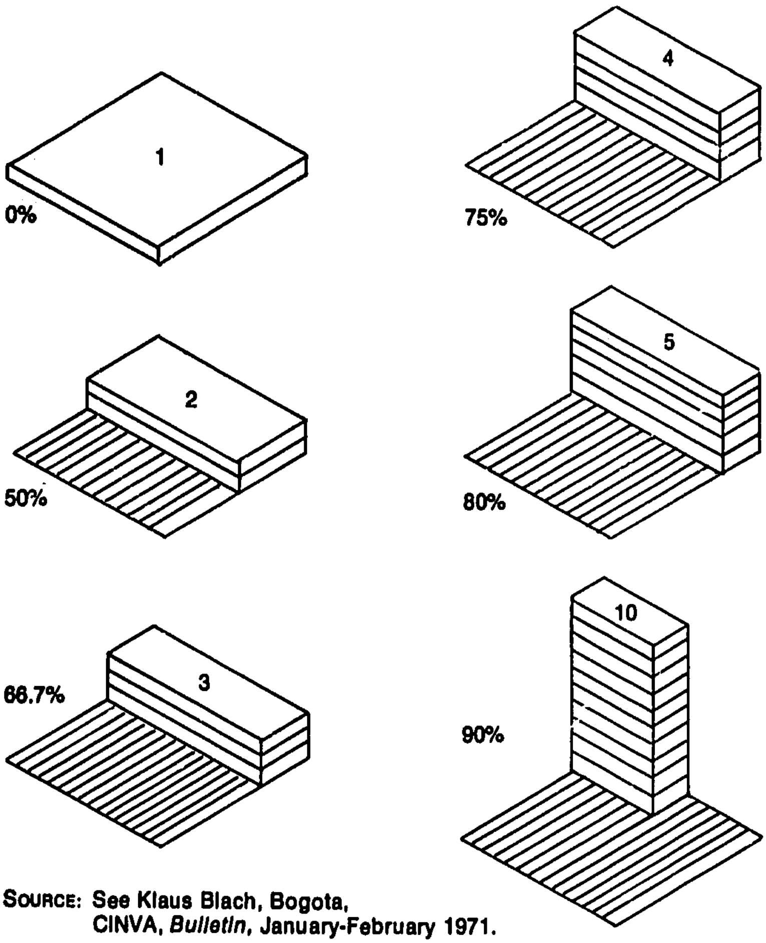
The only way to salvage any case for ISB, given quality, as we have said, is to bring in site costs and to attribute to ISB any savings from higher density. One can compare, rather illogically, low density conventional single family housing with ISB high-rise apartments, assign a very high value to the land that is saved, and claim that ISB made it possible. In fact, causation runs the other way; only high density, a minimum of 400 dwelling units per hectare, makes ISB possible by lowering equipment installation and panel transportation costs per unit.

Perhaps a surprising oddity is that much less land is saved by increasing net density from 200 to 400 dwellings per hectare than by raising it from 100 to 200. Moreover, what little is saved at higher densities comes at sharply increasing costs per square meter. This section will explain why that is so and the consequent implied limits for high-rise building and ISB.

Part of the answer comes from geometry and the difference between changing net and gross densities. Net density here refers to that on residential sites, while gross density takes into account land needed for shops, schools, playgrounds, roads, and other facilities common to a residential sector.

Suppose 50 households per hectare live in two-story row housing, taking up half the land space. Public amenities lie outside the area. How much open space can be gained by four- and ten-story buildings? As Figure 1 shows, a shift from two to four stories releases 25 percent of the total area of 1,250 square meters per story. But a move from four to ten stories releases only an additional 15 percent, or 250 square meters per story; diminishing returns once again. A second identical ten-story building can be put on the site, but if the occupants come from similar two-story housing elsewhere, this will release no more square meters of land per story. On the occupied hectare, meanwhile, net density will have doubled to 100 households. Gross density will have changed only insofar as not all of the second released hectare is needed for additional schools, stores, and parks for occupants living on the first.

The diminishing growth rate of gross density with higher dwellings has been estimated for India by R.G. Gokhale, assuming equal town



SOURCE: See Klaus Blach, Bogota, CINVA, *Bulletin*, January-February 1971.

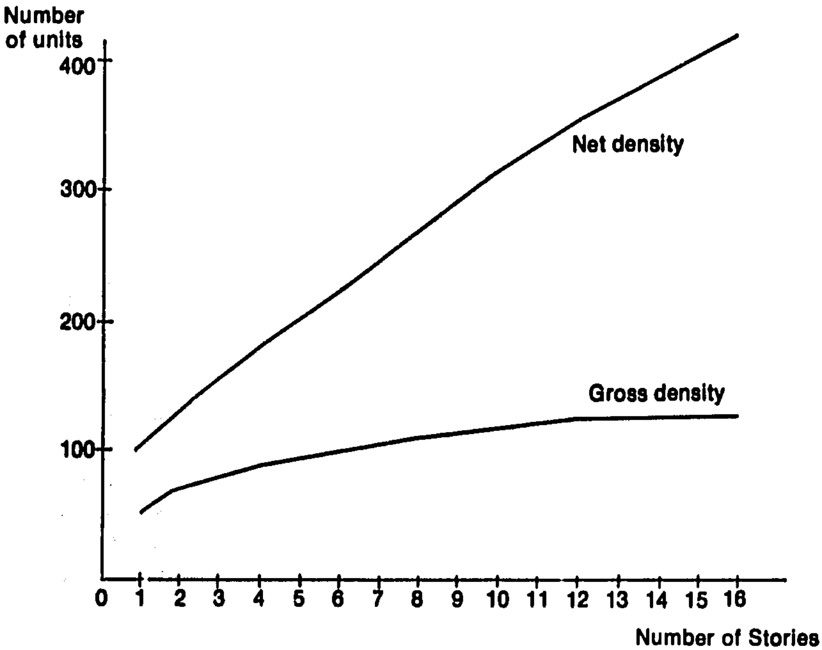
Figure 1. ***Building Stories and Open Space as a Percentage of the Initial Site***

planning standards for open spaces and community facilities. The results are shown in Table 16 and Figure 2.

Table 16. ***Changes in Number of Building Stories and Gross Density, India***

Rise in number of storys	*Percentage increase in gross residential density*
From 1 to 4	53
4 to 8	21
8 to 12	14
12 to 16	3.5

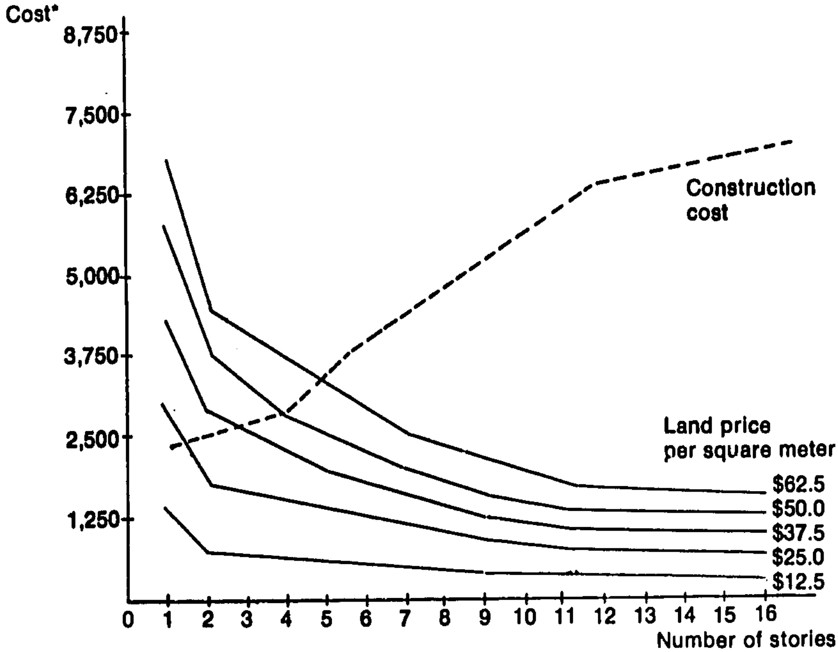
SOURCE: R. G. Gokhale, "Some Socio-Economic Aspects of High-Rise Housing," paper delivered at the National Conference on Tall Buildings, New Delhi, India, 22–24 January 1973.



SOURCE: R. B. Gokhale, "Some Socio-Economic Aspects of High-Rise Housing," paper delivered at the National Conference on Tall Buildings, New Delhi, India, 22–24 January 1973, p. II–2.

Figure 2. ***Number of Dwelling Units of 55.74 Square Meters per Hectare for Varying Numbers of Stories, India***

Rising density lowers dwelling costs by decreasing the amount of land needed per unit. Since density can rise only at a diminishing rate, the corresponding cost reductions will also take place at a diminishing and finally negligible rate. Meanwhile, construction costs will rise at an accelerating rate beyond four or five stories because of extra expenses for elevators, special foundations, fire protection, stand-by generators, and circulation space. In India per-square-meter construction costs for an eight-story apartment building are nearly double those for a four-story building. In Colombia the square-meter construction cost of conventionally built thirty-story apartments was 40–60 percent above that of four or five-story apartments, and double or triple that of single family housing.[5] In Great Britain in 1969–1971, whether conventional or ISB, high-rise council housing flats cost about 25 percent more per



SOURCE: R. G. Gokhale, "Some Socio-Economic Aspects of High-Rise Housing," paper delivered at the National Conference on Tall Buildings, New Delhi, India, 22–24 January 1973, p. II–5.

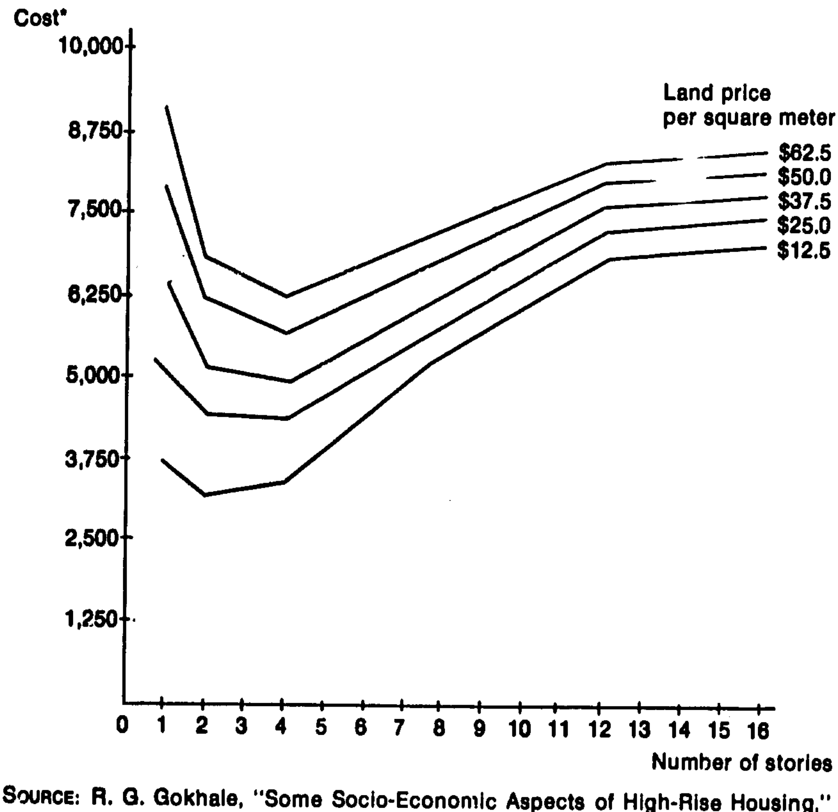
NOTE: For land prices from $12.5 to $62.5 per square meter.

*Cost of one dwelling unit of 55.74 square meters

Figure 3. ***Land and Construction Costs per Dwelling Unit of 55.74 Square Meters for Varying Numbers of Stories, India***

square meter than two- to four-story ones and 67 percent more than single family housing. For each type, ISB was 5–7 percent cheaper.[6] The British differential is less than the Indian because the steel-labor price differential is less. Indian low-rise buildings can use labor and masonry to reduce the quantity of higher priced reinforcing steel.

Unit dwelling costs are minimized at a height where the rate of *decrease* in land costs equals the rate of *increase* in construction costs, that is, where marginal costs are the same. Gokhale has estimated this point for India under alternative assumptions about the price of land per square meter, as shown in Figures 3 and 4.



SOURCE: R. G. Gokhale, "Some Socio-Economic Aspects of High-Rise Housing," paper delivered at the National Conference on Tall Buildings, New Delhi, India, 22–24 January 1973, p. II–6.

*Cost of one dwelling unit of 55.74 square meters

Figure 4. ***Cost of Dwelling Unit Including Cost of Land for Varying Numbers of Stories, India***

When the price per square meter is only Rs. 100 (about US$12.50 in 1972), two-story dwellings are cheapest. At Rs. 200 (US$25), two- and four-story housing costs the same. Four-story housing remains cheapest at all estimated higher land prices. Two-story housing remains cheaper than eight-story flats even if the land price rises to Rs. 500 (US$62.50) per square meter.

Similar estimates for India have been made by C.B. Patel. According to him, unit construction costs of a dwelling in a four-story building will be 20 percent above those of a two-story house, and in a twelve-story building they will be 130 percent more. When the price of the site exceeds half the construction cost of the two-story dwelling built on it, four-story dwellings become more economical. From this point on, the land price must rise by a factor of eight before twelve-story buildings yield cheaper dwellings than four-story ones. Compared with two-story dwellings, high-rises will not be competitive until the land costs twice as much as the house.[7]

In Colombia, the site must cost 4 percent more than a single family house before it pays to switch to four-story apartments, and 59 percent more than the structure before twelve-story high-rises become cheaper than single family houses. If 43 percent is typical as the ratio of the site cost to the single family housing construction cost, site value must nearly quadruple before high-rises become cheaper.[8]

Whether or not land costs will rise depends on the rate of growth of cities and upon the extent to which transport systems keep pace. The subject has not been thoroughly explored in most cities, but it could be that, when adjusted for inflation, land speculation has not been as lucrative as widely suspected. In one city where usable records are available, Bogota, it appears that the average real price of land did not rise more than 2–3 percent annually during the 1960s.

Even if the scarcity of land is judged in physical rather than current financial terms, urbanization may aggravate it less than is commonly supposed; high-rise building may alleviate what problem there is in only a minor way at an exorbitant cost. By switching to high-rises from two- to five-story dwellings in India, about one-third of the residential land can be saved. But since the residential sector of cities in India (and elsewhere) is only 30–40 percent of the area, the spread of the city will only be reduced by some 10 percent. Even if the Indian urban population doubles (an additional 120 million people) and if these are settled at the low rate of 240 persons per hectare, only 10,000 square kilometers, or 0.32 percent of the national area, will be needed. To save 500 square kilometers out of 3,162,000, one must double construction costs in a capital-intensive way, obviously a misallocation of resources.

Similar estimates have been made for Great Britain by P.A. Stone. In the 1960s the density of settlement was 59 rooms per acre with a residential composition of 74 percent single family houses, 18 percent low flats, and 8 percent high-rise apartments. At this rate, about 600,000 additional acres of land would be needed by 2004. If the density were raised to 69 rooms per acre (or by 17 percent), 110,000 acres would be saved; at 80 rooms per acre (36 percent higher density), a further 90,000 acres would be saved. To save each average acre of farmland (worth about U.S. $480), construction costs would rise by $72,000 per acre saved. In physical terms, the proportions are much like those of India: Higher densities can save one-third of residential land but perhaps only one-eighth of urban land. If the British population rises to 72 million by 2004 and a rise in rooms per inhabitant is projected, high-rise building can still only save about one-third of one percent of the national area. Rises in agricultural productivity can offset this loss in a single year, and recreational space would not be seriously curtailed.[9]

Industrialized Building in Advanced Countries

Before looking at the record of ISB in developing nations, one should know how it has fared in advanced countries. Until the 1950s a common lament among the advanced was that the Industrial Revolution had never transformed the building industry and that this step was long overdue. The lament was unjust.

Some Early History

As iron became cheap after 1815, cast iron ornaments replaced terracotta on British buildings, and even John Nash painted cast iron columns to look like stone. Iron columns had been used for interior supports in cotton mills as early as the 1790s. By the 1830s, I-beams and inverted T-beams were common in England and France. Cast glass also dates back to the late eighteenth century, and in unpolished form it found wide use in factory and railway station roofs. The combination of prefabricated iron posts and beams with glass panels allowed the astonishingly rapid construction of the famous Crystal Palace in London in 1851. Reinforced concrete was used in the late nineteenth century and is a scientific combination of two other industrialized products, cement and reinforcing steel.[10]

European and North American two-story brick and wooden dwellings of the past century may resemble eighteenth-century houses, but they were produced quite differently because of the Industrial Revolution. Cheaper iron, steel, and power led to numerous changes in carpentry because of cheaper nails, saws, and other tools. Thin, mechanically sawed softwood took the place of axe-dressed hardwood in a radically different framework, the "balloon frame," commonly attributed to Augustine D. Taylor of Chicago, and first used in about 1833. Brickmaking was transformed by pugmills for grinding clay, extrusion machines, mechanical wire-cutting, and clampburning. By 1856 there were 230 English patents for brickmaking.[11]

Paradoxically, prior to the Industrial Revolution, design, materials production, and sitework were a far more integrated activity than afterward, approximately the sort of coordination that industrial systems building is supposed to create. For example, in the eighteenth century the title "carpenter and architect" was still common and by no means degrading. Bricklayers often made their own bricks. Specialized general contractors did not replace master craftsmen working for the owner or architect (on a cost-plus system) until the first third of the nineteenth century. Eventually, in 1887, British architects were prohibited from organizing sitework and having a direct stake in low costs, with the well-known result that the client's maximum budget became their minimum. All these barriers among building professions were needed, however, because the Industrial Revolution had produced novel materials and designs, hence uncertainty, hence a great scope for incompetence and fraud. The barriers among specialties, in effect, created a system of frontiers with incentives for policing the quality of materials, safety of designs, and reliability in execution. Much European housing was erected without this system of safeguards; nevertheless, the system was widespread enough to make buildings cheaper and safer and building technology less dynamic.[12]

Great shortages of housing, building materials, and skilled labor after both world wars led to experiments with easily assembled building components made of unconventional materials. The Dutch had a competition among forty systems near Amsterdam in 1924 and selected ten for further large-scale trial, including some with prefabricated concrete panels. Germany had two factories for lightweight concrete panels that could be assembled into a house in one and one-half days at a presumed saving of 10 precent. In 1928 a British writer observed that "a number of buildings utilizing precast concrete components have been constructed by some enthusiasts," and a Cast Concrete Producers' Association was formed. But as competing bricks or wood for ordinary concrete formwork once more became abundant and cheap, these novelties disappeared, only to be revived again during and after World War II.[13]

The Rise of ISB after 1945

After 1945 the French and Danes took the lead in developing industrialized systems building, but other countries followed; eventually about 400 systems were available for commercial licensing. Some of these were bought by the Soviet Union, which set up more than 300 building factories with simplified production systems that could turn out up to 13,000 dwelling units per factory annually (the Koslov system). Since descriptions of these systems are widely available, they will not be repeated here, except for the unsuccessful Larsen and Nielsen, Shelley, and Estiot systems mentioned in Appendix D. Important to note are the special conditions of postwar Europe: a large volume was demanded quickly; labor was scarce and wages rising; high densities were customary; hopeful occupants had no alternatives; and governments could give subsidies for "a decade of 'incubation' for their industrialized producers, without which, most, if not all, would have economically perished."[14]

Since these European conditions never prevailed in the United States, ISB has made little progress in that country, although housing structures were not vastly superior. On the contrary, with an "operation breakthrough" during 1968–1973, costing $137 million the government hoped to solve housing problems by promoting European or other novel building methods. A committee of the National Academy of Engineering was set up to assess the role that large corporations might play in developing a sophisticated mass production housing technology. Over 700 housing systems and subsystems were codified, and a computer model, focusing on constraints that had to be overcome, was developed. The committee concluded that any investment to restructure the industry would be so unprofitable as to be "extremely discouraging" and at best would reduce costs by less than 10 percent. European standards of density and amenities simply did not fit American tastes, and production rates of thousands per week would be hard to reach and to sustain, except for many components that were, in fact, already being produced, distributed, and installed.[15] As the president of one company that was "shaken out" expressed it:

> There are savings to be made in mass producing housing. Unfortunately, these savings are dissipated by the cost of protecting modules against weather and protecting them for shipment. Then there is the cost of transporting them to the site. By the time you are through, you have dissipated much of the savings derived through mass production. Also conventional construction today is far more efficient than it used to be . . . . In addition, the more we got into this, the more we realized that we were limited in the number of designs we could produce. Obviously, the term "mass produce" indicates some consistency or conformity, and we found that people aren't willing to buy . . . . I've concluded, therefore, that the future isn't in modular housing, but modular components. For example, a bathroom . . . . The lesson has been costly for us. We invested $7 million in this venture.[16]

The director of architecture for the Metropolitan Life Insurance Company, one of the largest financial intermediaries in housing, has said: "Our firm would like nothing more than to get behind a red-hot system, but it seems that they all manage to fall flat on their faces, even when you give them the volume market they always say they need. Maybe they'll go somewhere in the future, but it's doubtful for residential markets because repetitive design is hard to sell. Most system-built middle- and high-rise residential buildings that I've seen have ended up looking like hospitals or prisons."[17]

While vainly trying to follow in the European footsteps, U.S. housing authorities should have noticed that, in fact, Europeans were turning toward low density housing in suburbs along the American pattern and finding that ISB had its limits for such plans. In almost all northwest European countries, apartment blocks had excessive vacancy rates by the early 1970s, while suburban housing was in great demand. If public wishes were to be followed, as was likely in these democracies, then both urban strategy and building technology had to change. Meanwhile, along the Mediterranean and in Eastern Europe, high-rise blocks and ISB remained acceptable.

A misconception had been that North American cities were settled at low density because land was cheap in a vast, sparsely settled continent. But the amount of land in farms and ranches in a huge hinterland has little effect on the price of urban sites. This high price is caused by the advantages of high density. Urban industrial, administrative, and commercial employment centers are likely to be densely concentrated because these activities run more smoothly when close together. If employees cannot afford time and money traveling to work, settlement around the employment centers will be very dense, raising land values, which further compels dense settlement. To keep rents per family low, although rent per hectare is high, the number of families per hectare must be still higher in proportion.

As incomes rise, workers can afford to travel farther to work, and they can buy or rent more urban space without raising its share in their budget whenever the price per square meter falls with distance from employment centers. Remember that area available will normally quadruple as distance doubles. Where the craving for space is high, families may even raise the land share in the household budget (an income elasticity of demand exceeding unity), in which case the expenditure is still likely to rise at a lower rate than the acquisition of space. All these interactions are very complex and cannot be fully disentangled here.[18] The point is that North American cities have always been of low density, not because space was ample, but because the resources of the continent made settlers, both rural and urban, prosperous. As northwest European countries have attained comparable income levels, they have sought comparable low densities — a house with a larger garden or at least an apartment complex that blots out less sky.

A few examples from 1973 country memoranda to the Housing, Building, and Planning Committee of the UN Economic Commission for Europe illustrates the trend and its effect on ISB.

The 1970s in Continental Europe

In Sweden, housing authorities noticed "a shift in demand away from flats in large blocks towards other forms of housing with direct contact with the outdoor environment." In 1973 more single family houses than apartments were started. The high rate of construction during 1969–1972 of over 100,000 dwelling units per year had relieved the housing shortages enough to cause "a fall in the demand for new flats in multi-family blocks, thus causing an increase in the number of flats standing empty." The result has been stagnation in concrete prefabrication. "It has even been necessary to close down a number of manufacturing plants while others are running on a reduced basis." Advocates of ISB, however, believed that its decline was due to insufficient rationalization and integration, "the fact that secondary elements and interior fixtures have not been adapted to the needs of prefabricated concrete frameworks .... As soon as we have succeeded in producing the right combination ... concrete components will have the opportunity of showing their true competitiveness." Industrialization of single family houses, meanwhile, had brought no firm beyond an annual volume of a few hundred per year.[19]

Denmark also experienced "a major swing in housing demand towards single-family housing." With vacancies approaching 5,000 units in nonprofit apartments, the government lowered rents and contract terms for such buildings despite rising construction costs. But the vacancy rate did not fall. Because of "general affluence and tax concessions," the swing to owner-occupied single family housing continued. In addition, "strong personal preferences for the special qualities of this type of housing" were detected in studies by the Building Research Institute. Thus, in one of the home countries of ISB, demand is shifting from a sector that used it to an 80–90 percent level in Copenhagen, or 60–70 percent elsewhere, to a use in single family housing for only 20–30 percent of units.[20]

France is the other outstanding pioneer of industrial systems building. By 1973 French housing authorities could say that building with exclusively traditional methods had practically ceased. Construction of hospitals, primary schools, and offices was particularly industrialized. Statistics on the share of housing that was mainly industrialized are not available, but it was unquestionably high, around 42 percent for the most advanced heavy systems alone in 1970 (that is, not including metallic systems, light-weight cladding panels, and so forth).

Altogether, France had built 7.7 million dwelling units between 1945 and 1974 and then found that the remaining housing problem was "qualitative," to improve the environment, rehabilitate urban centers, give apartments better insulation, and especially to develop single family housing. Of course, countering rising costs was seen as a perennial challenge.

Of the 555,000 dwellings started in 1972, 43 percent (240,000) were single family units; only about 25,000 were built in sets of two or more. But nearly 49 percent of all dwellings (270,000) were in projects of more than 50 units each, hence probably industrialized. With this division of the market, building systems factories were operating at only 60–70 percent of capacity even on a one-shift basis. As the share of single family housing rose, further innovations were needed to sustain or promote industrialized building, for example, lighter interchangeable components with multiple functions. Moreover, France wished to consolidate with further research its leading position as an exporter and international licensor of buildings systems.[21]

In the Netherlands, multistory blocks reached their maximum share in 1967 with 45.3 percent of housing production. By 1973 a 20 percent share was considered the upper limit because multistory apartments were deemed unsuitable for families with small children. "People felt dissatisfied with the massive character of the new neighbourhoods." To encourage single family housing, the government eased credit terms and generated such a volume of applications that consideration of new ones had to be temporarily suspended. Nevertheless, the share of single family housing rose from 55 percent in 1967 to 73 percent in 1972.

The problem with multistory Dutch ISB, based on French and British models, was high cost and insufficient quality. As a remedy, the government granted subsidies after 1968 for experimental buildings to raise quality even at additional expense. Exterior decoration with aluminum and wood and other forms of differentiation were supposed to attract occupants. In some cases prospective customers were to be given a voice in determining the layout of dwellings. "There still remains the desire for greater variation and flexibility in order to avoid architectural impoverishment and uniformity." Virtually no modular boxes were used, and the limited possibilities for variation with large panels were considered a severe drawback. If economies were to be realized from mass production, they would come from standardization of smaller, especially interior, components.[22]

England and Wales

British industrialized building began with schools but did not gather much momentum until the government encouraged local authorities to use it in 1962–1963. As a percentage of all dwellings for which tenders were approved by local authorities and new towns, those with ISB rose from 21 percent in 1964 to a peak of 42.6 percent in 1967, followed by a decline to 18.4 percent in 1972. As Table 17 shows, peaks in the share of "dwellings under construction" and "completed" followed with a two-year and three-year lag.

From Table 18 one can see that the shift from ISB in Great Britain was not due to disappointment with its relative efficiency. For apartment buildings of five or more stories, ISB was more efficient from the first recorded year, 1964, and generally increased its margin in terms of cost per square foot. For houses and low-rise apartments, ISB did not become cheaper until 1969, but it continued to widen its margin, even as its popularity fell.[23]

Although its popularity was fading in the early 1970s, the industrialized building had clearly become more efficient than traditional methods. On the average, as shown in Table 19, row 6, industrialized building was 13 percent cheaper per square foot. Moreover, this difference did not depend on great economies of scale associated with industrialized as opposed to traditional building. The average industrialized scheme involved 78 dwellings, compared with 35 for traditional developments, not an overwhelming difference. The slope coefficient associated with volume seems to give a considerable edge to industrialized methods only in the case of two- to four-story flats and maisonettes (see Table 19, column 2).

Comparing 1972 with 1966 in terms of approvals, all local authority building had shrunk to 45.6 percent of its former level. Industrialized building had fallen more, to 24.9 percent, and industrialized high-rise building still more, to a mere 7.1 percent of its 1966 level. Traditional high-rise had fallen to 19.2 percent.

Changing relative importance in times of contraction can reflect a "shakeout" of inadequate systems. By far the most important remaining system was one not radically novel but using prefabricated formwork for pouring concrete, called Wimpey no-fines. Ten other systems accounted for half of the remaining completions, or about 37 percent. Rationalized systems using bricks held their own well. The most radical change, factory-made boxes or "modules," ceased to be made after 1970. From 1970 to 1972 the share of heavy load-bearing

Table 17. ***Industrialized Dwellings as a Share of All Dwellings Built by Local Authorities and New Towns in England and Wales, 1964–1972***

Year	*Percentage of all dwellings* In tenders approved (net)	Under construction at end of period	Dwellings completed
1964	21.0	16.2	14.4
1965	29.1	21.9	19.2
1966	38.6	27.3	26.3
1967	42.6	34.2	30.8
1968	39.4	39.6	34.2
1969	30.1	41.1	38.0
1970	19.4	30.1	41.3
1971	18.8	24.1	32.7
1972	18.4	18.8	26.1

SOURCES: *Housing Statistics*, no. 17 (May 1970): 28; and *Housing and Construction Statistics*, no. 4 (1973): 34.

Table 18. ***Area and Cost per Square Meter of Industrialized and Traditional Dwelling Tenders Approved by Local Authorities in England and Wales, 1964–1971***

Type of dwelling and year	*Industrialized*		*Traditional*[a]		*Ratio of industrialized to traditional cost*
	Average area, in square meters	*1970 average cost per square meter, in U.S. dollars*	*Average area, in square meters*	*1970 average cost per square meter, in U.S. dollars*	
Houses and bungalows					
1964	82.5	$ 81.92	76.1	$ 77.18	1.06
1965	82.7	85.57	78.0	82.45	1.03
1966	84.7	87.08	80.2	85.47	1.02
1967	83.3	90.20	80.2	88.59	1.02
1968	86.0	88.05	83.0	87.73	1.00
1969	85.0	88.27	79.8	91.39	.96
1970	85.6	92.25	80.0	95.80	.96
1971	84.4	100.97	79.1	109.58	.92
Flats in 2 to 4 stories					
1964	65.9	106.03	59.5	102.69	1.03
1965	63.6	110.23	61.1	109.36	1.01
1966	64.6	118.30	62.3	113.24	1.04
1967	63.3	117.44	61.8	111.30	1.05
1968	63.9	114.32	62.0	111.62	1.02
1969	58.9	121.42	55.6	123.25	.98
1970	59.5	122.39	54.3	130.14	.94
1971	58.3	131.32	54.1	148.65	.88
Flats in 5 to 9 stories					
1964	60.0	140.15	60.7	143.38	.98
1965	62.4	143.92	61.5	151.45	.95
1966	65.7	150.38	62.5	127.66	1.18
1967	65.8	145.75	64.2	152.74	.95
1968	70.1	133.91	63.4	154.14	.87
1969	65.2	145.75	63.3	155.76	.93
1970	64.7	163.62	63.4	150.70	1.08
1971	65.2	160.49	59.2	188.91	.85

SOURCE: *Housing and Construction Statistics*, various issues (London: Department of the Environment).

NOTE: Figures for 1964–1968 include data for new towns and in some other ways are not strictly comparable to later years. Excluded are figures of the London Council and Greater London Council.

[a] Figures may include some ISB not identified as such at the time of approval of the tender.

Table 19. ***Cost of Dwelling Superstructure with Industrialized and Traditional Building Methods in England and Wales, Average and as a Function of Volume in a Development, 1972 U.S. Dollars per Square Meter***

Type of dwelling	*1 Intercept*	*2 Slope coefficient for volume (number of dwellings)*	*3 Average cost, in U.S. dollars per square meter*	*4 Ratio of industrialized to traditional cost*
House and bungalows				
1. Traditional	9.72	−.0096	$102	
2. Industrialized	8.86	−.0024	94	.93
Flats in 2 to 4 stories				
3. Traditional	14.04	.0010	151	
4. Industrialized	12.36	−.0072	129	.85
All dwellings				
5. Traditional	10.68	.0096	119	
6. Industrialized	8.86	.0096	103	.87

SOURCE: Directorate of Economics, Department of the Environment, London.
NOTE: Regressions were run for 11 districts of England and Wales. Each statistic consisted of the average cost per square foot in the district and the average number of dwellings in a local authority housing scheme or development. By 1972, high-rise flats (five or more storys) had become too rare to allow this type of statistical comparison. Foundations, utilities, pavings, and walls would increase all estimates by about 30 percent.

panels fell from 44.1 percent to 31.5 percent of industrialized dwellings completed.

From 1970 to 1972, 20 British industrialized building systems went out of use, while half a dozen new ones appeared. The total number in use declined from 95 to 71.

The decline from favor of ISB seems to be due to a change in taste, or rather, to a natural recovery of taste for low density and variety. As the 1973 *Country Memorandum* stated: "Systems which have not shown a marked flexibility have been at a severe disadvantage when in competition with traditional building techniques. Furthermore, some systems are only economic for high-rise buildings and in recent times for social, aesthetic and environmental reasons, there has been a public reaction against such buildings."[24]

Export Technology: One Case

Meanwhile, the Building Research Establishment (BRE, including the Building Research Station) of the Department of the Environment was promoting an ISB system of its own design for export from Great Britain to developing countries. This system consisted of 3.5-ton panels and slabs made by a vertical casting battery at the construction site and assembled as four- to five-story apartments. It was claimed that this BRECAST system "represents the simplest possible solution which combines resistance to earthquake forces with maximum architectural and planning flexibility. The production method is based on the well-tried BRE battery casting system which enables builders to obtain the benefits of industrialization . . . without the need for expensive permanent factories .... Every effort has been made to minimize and simplify plant requirements so that the plant cost can be as low as £10 (US$24) per flat."[25] Maximum labor involvement was also claimed.

Since an investment cost of $120,000 was foreseen, the implication of $24 per flat was a volume of 5,000 dwelling units, presumably without much moving of the battery and cranes from site to site. High densities were specified. Not included was the $12,000 to be charged for a set of four manuals and a three-week training course for three engineers. Foreign aid could possibly pay for these.

In August 1973 I saw the prototype buildings at the Building Research Station at Watford, England, and insofar as a layman can judge, they seem very ingenious. Designs show concern for shade and ventilation, plumbing is adroitly arranged, and conversion of space from small to larger units is possible. The eight-inch panels are joined and loads are transferred from upper to lower stories in ways that obviously reflect years of experience and experiments. For example, a comparatively small crane sitting on the building itself can handle the panels.

Nevertheless, the BRE did not seem to have much initial success in promoting the system overseas. An agreement to build 200 flats in Chile vanished with the government of President Salvador Allende. A more general obstacle was that architects in developing countries enjoy designing their own ISB systems. Furthermore, BRECAST was not very economical. Its optimistic advertised cost of US$37.50 per square meter in 1972 at a volume of 2,000 units (see Table 20) compares with realized costs of only US$34 for comparable conventional brick and *in situ* concrete buildings in India (see below). Naturally, costs per unit would be still higher if the volume of building did not reach 2,000 units. As Table 21 shows, at volumes of 500 or less, costs begin to exceed US$40 per square meter and reach US$76 when volume falls to 50 units. The assumption is that the casting battery costs $38,000 and the cranes and other equipment $48,000. Other costs are as shown in Table 20.

If the full 2,000 units can be constructed, one may estimate that some 80 to 100 workers will lose their jobs with a BRECAST system that is as efficient as traditional methods. This estimate assumes that, as in Colombia (see Appendix C, Tables C3 and C4), about 30 percent is the traditional labor cost share of the structural shell, compared with 22 percent for the BRECAST system. About $124,000 less would be spent on labor. If one may assume that construction workers are employed about 45 weeks out of the year and that two-thirds working on the superstructure are unskilled, then at the labor costs specified in Table 20 (90 cents per hour for skilled, 50 cents for unskilled), about 90 additional workers are needed with the traditional system.

ISB in Developing Countries

The combination that allows the use of ISB — willing occupants, high construction wages, low equipment and financing costs, and great

Table 20. ***Breakdown of Costs for a 48-Square-Meter BRECAST Dwelling Assuming 2,000 Units as the Volume of Construction, in 1972 U.S. Dollars***

Item		*Cost*
Foundations and utilities		*$ 348*
Roads and landscaping	$ 48	
Water, drainage, electrical services	168	
Foundations, stairs, roof finishes	132	
Precast superstructure		*$ 768*
Casting battery	$ 19	
Cranes and other equipment	24	
Concrete at $14 per cubic meter	259	
Reinforcement at $240 per ton	298	
Labor for production and erection at $43 per week skilled, $24 unskilled	168	
Finishing, labor, and materials		*$ 504*
Infilling walls, partitions, railings	$120	
Doors, windows	216	
Sanitary fittings	96	
Electric fittings	72	
Supervision and overhead at 11.1 percent		*$ 180*
Total cost		*$1,800*

SOURCE: Building Research Establishment, *Information*, September 1972, p. 2.

Table 21. ***Equipment, Variable, and Total Costs per 48-Square-Meter BRECAST Dwelling at Various Volumes of Output, in 1972 U.S. Dollars***

Volume: number of dwelling units	*Fixed cost*	*Variable cost*	*Supervision and overhead*	*Total cost*	*Total cost per square meter*	*Equipment cost as a percentage of total cost*
2,000	$ 43	$1,577	$180	$1,800	$37.50	2.4
1,000	62	1,577	182	1,821	37.94	3.4
500	173	1,577	194	1,944	40.50	8.9
300	288	1,577	207	2,072	43.17	13.9
200	432	1,577	223	2,232	46.50	19.4
100	864	1,577	271	2,712	56.50	31.6
50	1,728	1,577	367	3,672	76.52	47.1

SOURCE: Building Research Establishment, *Information*, September 1972, p. 2

land scarcity — is not likely to prevail in many parts of the world, particularly not in developing countries.

Cases from Several Continents

In some intermediate countries, ISB has been marginally successful. Singapore is an island of only 60,000 hectares, or about 300 square meters per inhabitant in the early 1970s. A more than 10 percent real national growth rate yielded a per capita income of $959 in 1970. During the 1960s, 120,000 dwellings were built at an average cost of $4,100. Dwelling construction was thus a leading sector, with a 5.1 percent share of GNP by 1972. (Cost per square meter ranged from US$52–$60.) High-rise building was common, but construction mechanization was only beginning in 1972. Dumpers, mixers, motorized winches, air compressors, and machines for cutting and bending reinforcing steel were just being introduced. ISB was studied, but not used.[26] In another example, after a half dozen systems failed in Venezuela, the confluence of economic and physical circumstances in Caracas reached a point where the Banco Obrero could support an ISB project, "Vivienda Venezolana," for fifteen-story apartment blocks made of seven-ton panels eight meters long. South Africa found that prefabricating panels out of ordinary bricks led to savings in multistory buildings when cranes were available. The use of cranes also made a difference in Israel. There, prefabrication of lintels, beams, slabs, window frames, and stairs — even single items on the site — could save one-quarter to two-thirds of that component's cost if a crane was readily available.[27]

More often, systems were failures, introduced with much fanfare, tried once, and then forgotten, their cranes and frames rusting among weeds. Current examples exist in Uganda and Egypt. But the depressing part is that these failures have now been accumulating for over two decades, dating back to the 1952 Schokbeton houses of Ghana, then known as the Gold Coast. The Dutch Schokbeton system made individual houses out of 90-centimeter panels weighing 123.75 kilos with equipment then costing about US$1 million. Quality was low because buildings were poorly designed and because panels were to be bolted together in a way that would (unintentionally) assure rapid deterioration in the tropics. Costs were about 80 percent higher than estimated, or 60 percent higher than those of concrete block walls. The details can be found in the report of the United Nations Technical Assistance Mission that appraised the project in late 1954. The mission saw no saving in the process, recommended that it be abandoned, and added a lengthy condemnation of the studies that had led to its adoption in the first place.[28]

Other attempts during the 1950s involved houses made entirely of metal. In Zambia, then known as Northern Rhodesia, the Commissioner of Rural Development was under the impression that steel-framed, metal-roofed houses could be competitive with those made of sun-dried bricks costing £150, not including water or electricity. Government loans were available for the metal houses during 1957–1959, but this type of system was no more apt for the time and place than the 3,200 aluminum houses designed for and sold to Colombia in 1955.[29] Their cost was too high.

Although expensive ISB is least suitable for housing the poor in developing countries, proliferation of slums led to interest in systems, panels, and prefabrication of all types. A Peruvian architect saw the French and Danish systems on a European trip in 1957, and four years later he had his own patent for a simplified system of panels, called *Listos,* one to five meters long. He also had a factory, cranes, and 135 workers. The system was supposed to reduce site labor by 39 percent in typical cases. A few office buildings, supermarkets, and factories were built, but after some trials in housing, the method did not spread for that purpose. The greatest market for Listos seemed to be as quickly erected fences to protect urban lots against squatters. Later, it was adapted to rapid reconstruction after an earthquake.

Other attempts to prefabricate the building shell in Peru did not get as far as Listos. Some of these were proposed by North American firms to obtain USAID financing in joint ventures since innovative ideas received a few extra priority points. Some were promoted as part of the Proyecto Experimental de Vivienda (PREVI), sponsored by the United Nations. When costs turned out to be not as low as claimed, but two or three times those of conventional construction, interest in the systems faded rapidly. As did other countries, Peru already had its large housing project, San Felipe, that had been intended for the poor but, when finished, could only be afforded by the upper middle class. The principal innovations that succeeded were very much like those described for Colombia in Appendix C.[30]

In the Philippines a National Housing Corporation was organized in 1968 by the social security systems, the Development Bank, and the National Investment Development Corporation and capitalized at 100 million pesos. Industrialized prefabricated residential construction was its purpose. Four factories were built to produce components for an annual minimum volume of 12,000 dwelling units. After two years of production, lack of demand and technical problems kept monthly production down to 125 units, that is, 12.5 percent of capacity.[31]

In five Central American countries a pilot housing project was carried on during the late 1960s under the auspices of the United Nations Inter-Agency Committee on Housing and Urban Development. Four countries used concrete blocks as the principal building material, and Nicaragua experimented with panels cast on the site. Resulting square-meter costs were as follows for dwellings of comparable size:

Country	*Dwelling type*	*Area, in square meters*	*Cost per square meter, in U.S. dollars*
Nicaragua	N-1	52.2	45.05
	N-2	55.7	39.03
Guatemala	G-2-C	58.6	17.73
	G-3-A	58.6	15.60
El Salvador	ES-3	49.0	25.40
	ES-4-1	53.4	35.43
	ES-4-2	54.0	37.80
Honduras	H-2	50.3	23.66
	H-3	54.0	23.80
Costa Rica	CR-1	50.3	20.68
	CR-2	54.7	24.86

Once again, building with panels proved most expensive, although it was not the only factor that raised Nicaraguan costs.[32]

In those developing countries that allowed no important role to market forces or squatting in allocating the dwelling supply, the success of systems prefabrication could simply be decreed. One example is Cuba, although recent accounts suggest that ISB panels are being abandoned as too costly compared with labor-intensive methods. Another is North Korea. Only three basic models of four- to five-story dwellings exist in North Korea, and by 1963 these consisted of only 80 components, including large panels; 90 percent of North Korean housing was built in this fashion.[33] In China, prefabrication has risen at a much lower pace, especially in dwelling construction. In part, this preference may be due to misgivings about following any Soviet model blindly; but even in 1955, before the split, estimates had shown that single story houses had the lowest construction costs per dwelling unit. Failure to assign any value to land probably caused this difference to be overstated.[34]

Opposition to ISB

In every geographical region of the developing world, one or two countries have wisely had policies against excessive prefabrication and systems building. An African country has refused to give import permits for casting equipment for concrete components intended for housing. In one case a permit was even refused for equipment that was to be donated by a former ambassador to that country as an innocent gesture of goodwill. Some Latin American and Asian countries have withheld credit from housing projects that were to be constructed in a manner deemed insufficiently labor intensive. Sometimes the policies are tacit, since governments do not like to be on record as being against "technological progress." In such cases, the owners of systems plants and patents often feel bewildered and imagine that failure to obtain approval must be due either to bureaucratic inefficiency or to corrupt favoritism. At other times, promoters know the specific high official who could approve if he did not have this absurd (in their view) preference for employment over low cost efficiency. The promoters seldom realize that if wages, equipment prices, and interest were at a level consistent with relative scarcities, industrialized systems building would be neither low cost nor profitable, even with their optimistic assumptions about volume and efficiency.

Mexico

Mexico is a country that has long been conscious of both employment problems and the need to develop proper technological opportunities. As early as 1944 the government engaged expert consultants to prepare a "technological audit" of key industries.[35] Twenty years later, in his inaugural address, President Gustavo Diaz Ordaz said: "The construction industry must modernize itself from its roots in cost-reducing ways." Architects, manufacturers, and others were invited to participate in a competition for the best novel design of a house for workers earning US$120–$240 per month. Of the six winning designs, two involved panel systems and two required elaborate prefabricated formwork to produce houses in the shape of drums or hexagons.

The government chose to promote none of these systems but to continue experiments with more traditional, labor-intensive designs. For rural families they considered concrete floor slabs with steel beams supporting an asbestos sheet roof. Forty covered square meters would cost about US$350. The structure would be completed by self-help. Simple urban houses would cost from US$700 to $3,500 (without land), or US$20 to $40 per square meter. All types were single story, rectangular, concrete block homes and seemed to achieve their economies primarily through omissions and the ingenious use of space.[36]

During 1965–1970 the volume of Mexican dwelling construction in the monetized sector fluctuated around 16,000 units per year. Late in 1970, the government announced an expanded program that would average 40,000 per year during the 1970s. It was recognized that this larger volume and technological progress might encourage use of certain light prefabricated elements, "but we must struggle to find a just balance between maximum use of labor and of those machines whose unrestricted employment could lead to general unemployment of the labor force. . . . So far it has fortunately . . . not been economical to install large industrial plants that, with high volume or heavy prefabrication would leave hundreds of thousands of construction workers unemployed."[37] Even if these methods did become competitive, said the report, the construction sector should remain labor intensive as long as its workers cannot be absorbed elsewhere in the economy.

In 1972, however, the government expanded the housing goal by an additional 100,000 units per year to be financed with a 5 percent payroll tax to be administered by a tripartite Instituto del Fondo Nacional de la Vivienda para los Trabajadores (Institute of the National Housing Fund for Workers). This agency engaged in all types of experiments, from rationalizing traditional components to seven-ton panel systems. During its first three years only 55,000 dwellings were provided at an average price of 100,000 pesos (US$8,000). Soon the 1980 goal was reduced to 85,000 units, and choice of building methods was henceforth left to private contractors. Employment promotion seems to require persistent ingenuity and, as does democracy, eternal vigilance.

India

India is another country that temporarily failed to resist industrialized systems building despite great poverty and underemployment. Certainly, the shortage of housing was immense; 12 million urban units was a typical estimate in 1973. Annual construction of 280,000 units was expected during 1969–1974, although household formation and migration alone would call for 2.7 million. The proportion of urban families in a city such as Poona occupying one room or less was higher than before 1940. In Ahmedabad about 65 percent of households occupied one room or less in 1965 and thus lived in a considerably smaller space than the National Planning Committee's minimum standard of 9.3 square meters per adult and 6.6 square meters per child. In Bombay, 6 percent of the population was homeless. Indeed, the Gujarat housing census showed an average of only 1.9–2.3 square meters per person, which compared with 3.7 square meters per convict specified in the jail manual. D. R. Gadgil observed in 1972 that "neglect of housing needs has been one of the gravest blemishes on the earlier plans" and objected to unrealistically high standards. The Hindustan Housing Factory had been established in New Delhi in 1956 and had produced hundreds of partially prefabricated dwellings, a negligible contribution. Gadgil concluded that "the expenditure of even large sums [on such prefabricating systems] could not make much impression on the existing situation."[38]

The annual reports of the Central Building Research Institute nevertheless show that increasing experimentation with prefabricated concrete components went on throughout the 1960s. Reinforced concrete lintels and 200-pound roofing slabs were reported as having been tested during 1962–1963. A pillar-panel system for prefabricated concrete houses of 51 square meters had been worked out by 1965. The twelve different types of components could all be cast in wooden molds and be handled manually. The 1966 report showed that large-panel prefabrication systems were being developed and that problems had arisen with shrinkage, cracking, suitable sealants, and insulation. Apparently, no concrete could give thermal comfort comparable to a 23-centimeter brick wall at reasonable cost. Nevertheless, experiments with heavy panels continued, using batteries and five-ton cranes for making two-story dwellings. By 1970 the large panels were being incorporated in public housing for New Delhi.[39]

Writing for the Calcutta Metropolitan Planning Organization in 1969, Zenon A. Zielinski declared that "large-scale mechanized prefabrication will be premature at the present stage of housing efforts in India. A simple style of prefabrication, without the use of expensive equipment or mechanization, is the need of the day."[40] A system of panels weighing 300–350 kilograms and incorporating Zielinski's ideas, called UCOPAN (Universal Concrete Panel System), was designed, and a panel factory began operations in Calcutta in 1971. Another was planned for Bombay. Some of the panel systems claimed to be somewhat cheaper than the US$34 per square meter of typical urban brick or concrete buildings. But even single room dwellings costing US$440 or so would remain far beyond the means of the 12 million poorly housed urban households.

In Poona, a factory for making lightweight concrete panels, called Siporex, was set up in 1971 with Swedish technology. The plant cost about US$3 million and presumably had an annual capacity for making components for 10,000 dwelling units. Adding transport and installation equipment, if all went well, fixed cost per unit might fall to around $100. The reaction of I.S. Uppal was that "it is therefore necessary to adopt some cheaper method of house construction by evolving a material which can be produced cheaply .... Prefabricated units [do] not appear to be an effective way to solve the housing problem of a poor country like India."[41]

In 1973 a group of Indian architects, planners, and economists also reviewed similar schemes and concluded: "We have tried them and they haven't worked. If we care we must think again and afresh. After all, people in India have housed themselves for thousands of years — without steel, without cement."[42] An economist in the group, Ashish Bose, opposed going back to traditional houses designed to last three generations. "Houses should be built to last for 30 years only. If this concept is accepted, we can do away with a whole lot of P.W.D. [Public Works Department] standards and . . . substantially cut down the cost," perhaps to US$13 per square meter. For a Bombay planner, Charles Correa, 45 years were enough longevity for a house.[43]

According to Mr. Jagmohan, Vice-Chairman of the Delhi Development Authority, reverting to thatch, mud, and wood "does not mean sticking to antiquated or old-fashioned systems or being conservative. It only means elimination of faked modernity. With limited financial and technical resources construction of so-called modern multistoried buildings with cement and steel for shack dwellers who migrate from the impoverished rural hinterland is out of place. Modern construction — ill-fitted cells and hideous inhuman settlements — is unnecessary."[44] Any progress in improving the housing situation depended on integrated economic and spatial planning, on a rational land use policy, and on a return to traditional construction materials.[45]

The Middle East

The experience of the Middle East should be included in this discussion, although technological building problems in that area were unlike those of other developing countries after the quadrupling of oil prices in the early 1970s. With a per capita income of $13,900 in 1975, Kuwait had reached a level double that of the United States; Qatar with $21,100 and the United Arab Emirates with $33,200 had gone far beyond that. Given a high priority for housing and a very small construction industry, governments of these countries found that they had to import both capital equipment and labor. Western ISB and Asian labor seemed to be the answer. When funds are ample, one does not spend much time estimating which approach involves the lowest subsidy.

The pressure to build rapidly and at almost any cost was such that the building industries of relatively poor neighboring countries were also affected. Among these was Jordan, with a population of 2.7 million and a GNP per capita of $439 in 1975. At one construction site with a labor force of approximately 300, the writer was told in December 1977 that about 65 skilled workers left for the Persian Gulf states each month! They were sure that they could earn much more there than the daily $6.60 (two dinars) that they made in Jordan. Under these circumstances, the Jordanian site was almost transformed into an educational institution.

Moreover, this site had already adopted a partially industrialized method of building, an aluminum standardized formwork system that gave an appearance of masonry after *in situ* pouring of concrete. This system, designed by International Housing, Limited, of Westport, Connecticut, had been used to build six houses per day for workers in a nearby refinery. Construction costs, without an additional 28.5 percent for urban infrastructure, had risen from $92 per square meter in 1975 to $132 in late 1977. The typical dwelling of 70 square meters was by no means luxurious. Nevertheless, many components were imported. Aluminum profiles for window frames came from the United States, the window glass from Turkey.

A more expensive building system was being used in 1977 to build 350 dwellings for employees of the Royal Jordanian Airline. This system, called TRUST, came from Thailand, where it had been developed by Pighal Opanukij. Hollow-core panels are manufactured on the building site by pouring cement over a row of pipes that are pulled out after the panel hardens. The hardening is accelerated by a simple device that is inserted manually into the pipes where it vibrates and makes the cement settle. The typical panel is 60 centimeters wide and 4.5 meters long, and some weigh as much as 3.5 tons. In Thailand, only eight different panel sizes were used, and a floor space of 40,000 square meters was said to be the minimum volume — about 400 dwellings. The system has also been used in Malaysia, the Philippines, Hong Kong, and Macao.

Application to Jordan was initiated by Mr. Hisham Nuseibeh of the Serene-Co contracting firm after finding other systems too complicated. Since the airline housing project had originally been designed for conventional construction, it involved eight apartment types and eight housing types of an average size of 200 square meters. Consequently, 59 different panel sizes and elements had to be made, and costs were estimated at $200 per square meter (without urban infrastructure). In terms of 1970 dollars, that cost would have been only $100 per square meter, but that is still far above costs mentioned elsewhere in this study. Nevertheless, in Jordan this cost was said to be 25 percent less than conventional construction (bricks plastered on both sides). The panels need no plastering and allow wiring and plumbing to be inserted through the hollow cores left by the pipes. It is unclear whether or not the way the panels are joined would meet building code standards in an advanced country, especially in a seismic zone.

An interesting aspect of this project was the composition of the labor force. Out of 200 workers, 120 worked in the precasting operation and 80 on erection and finishing. Half the labor force came from Taiwan and Thailand.

Conclusion

By now it should be clear that ISB in developing countries has generally failed, although not in every sense of the word. One should define *failure* before asking why it has occurred repeatedly for over two decades. After that, some policy recommendation should emerge.

The Anatomy of Failure

Failure can be structural, aesthetic, functional, financial, or economic. Structural failure can mean a sudden physical collapse, such as the 22 stories that cascaded down at Ronan Point, England, in 1968. Or it can be a slow deterioration because of rusting, seepage, and cracking, which occurred with the Schokbeton system on the Gold Coast. Either way, structural failure is physical, easily understood, readily photographed, and least likely to be repeated.

Aesthetic failures in housing range from unpleasant to grim and hideous, more often in the eyes of visitors than in those of occupants. If occupants shared that view, they could insist on being compensated with lower rents or lower monthly payments, unless, of course, they have nowhere else to move. If people can move out, aesthetic failure merges with financial failure — a process currently under way in Western Europe. Aesthetic failures can be photographed, but because of the merging with finance, the photographs cannot always be readily understood.

The concept of financial failure is not difficult in principle: Cost exceeds the selling price or rent of a dwelling. As a result, promoters of a particular type of ISB in a certain place will stop building because of bankruptcy or heavy losses. Costs can be too high because volume is insufficient or is reached with too much delay. In serious cases, costs are too high even with an adequate volume because of low productivity, breakage, and other unpleasant contingencies. In some instances the price or rent that can be charged will be lower than expected because prospective occupants refuse to pay more. In extreme cases, people refuse altogether to move in and to pay for housing they consider inconvenient, bizarre, or even dangerous.

Financial failure can always be overcome with government subsidies, often called "investments," on the grounds that these latter are less than the benefits that might accrue indirectly and invisibly to the public. But financial success, whether or not due to subsidies, will nevertheless be *economic failure* if all resources used in an ISB scheme could have been used more productively elsewhere in the economy or on other types of housing on the same site. The effect on employment is often a good preliminary indicator of economic failure. To build 2,000 dwellings, the BRECAST system eliminates about 90 jobs, the ARUV-Estiot system about 320. Yet, these are supposed to be relatively labor-intensive, low volume systems. Subsidizing building systems that simultaneously raise costs and unemployment is an arrangement that will appeal to most governments only temporarily.

Then why is economic and financial failure in one country so often repeated in others? Inability to photograph subsidized flows of money and high opportunity costs is no doubt part of the answer. Reasonably honest and clear cost records are almost impossible to find. The promotional literature of some systems sponsors is hard to believe, since many people suspect they might be shy about revealing all if they were in the promoters' place. But would not the victims of expensive schemes be willing to tell all? Perhaps, but when people advertise their mistakes, who listens? In any case, in the design professions it often seems to be more enjoyable to make mistakes than study those of others. Failure sometimes goes to designers' heads, and they tell us that logically by the year 2000 people will be living in diagonal geodesic contraptions of 200 stories with populations of 25,000.[46] But as Winston Churchill said, "we must beware of needless innovations, especially when guided by logic."

In any case, there have to be fashions in failure, since anyone can fail at just about any activity without previous training. What matters is *how* you fail. In building it is chic to fail with something novel, and since novel ideas do not come along often enough, one has to recycle old ones, first as "prefabrication," then as "industrialized housing," and currently as "systems building." Each verbal reincarnation provides creative opportunities for a new generation of designers. Unfortunately, the decline of high-rise ISB in Europe and its failure to catch on in the United States are interfering with this ecological conservation of old ideas. A ripple of fashion is nothing if it does not seem to be the wave of the future.

Still, most failures are probably due to neither fraud nor vain self-indulgence. They are honest mistakes in difficult terrain. It is easy to think that if one builds each house in 10 precent less time, one can build 10 percent more houses. It is hard to believe that fewer and cheaper components (per square meter) will lead to a more expensive structure just because of higher transportation and assembly costs. Furthermore, given the housing shortage and a neat, modern design, it seems incredible that salesmen, bureaucrats, and bankers should be unable to recruit a sufficiently large army of occupants for any needed volume. Why should one believe that just because costs *can* go up asymmetrically, they *will* go up? Finally, given the notorious climb of land prices in the past, how can anyone believe in low densities of settlement?

Mistakes on all these points, plus the tendency to believe that making mistakes is more honorable than doing nothing at all, has led to repeated failures with ISB. Not readily foreseen is the side effect of disastrous inflexibility in practice or most indirect repercussions throughout the rest of the economy. Housing policy, including its technological aspects, cannot really be made only by designers and technicians.

Protocol demands that such an assertion be followed immediately by a few policy recommendations for obtaining an optimum of housing built with an optimum of technology.

Some Brief Policy Recommendations

Jailing people for recommending ISB comes to mind but seems a rather extreme measure. Enrolling designers and promoters in economics courses might be insulting and a further waste of resources. Forbidding the actual use of ISB or even research to improve it in developing countries would also be unwise, but why should those who launch these activities not do so at their own expense? Occasionally, this kind of research leads to such components as prestressed lightweight ceiling beams that blend nicely with traditional construction. In that case neither penalties nor subsidies are needed. Zealots for promoting ISB are also helpful in promoting modular coordination, which, by improving the efficiency of traditional building, retitled "open systems," actually helps to forestall ISB.

The objective is to encourage the continued use of wood, bricks, tile, blocks, and perhaps *in situ* pouring of concrete. But how? To feel useful, government policy makers must have the impression that they are calling the shots, promulgating laws, issuing decrees, telling people what to do. Economists tediously but respectably tell them to correct the relative prices of capital, foreign exchange, and labor, which these policy makers often distorted in the first place. In the case of ISB, the building technique is usually so inefficient that the normal amount of factor price distortion in developing countries is not nearly high enough. Special guarantees and subsidies for dwelling projects and their promoters are needed, or conventional construction methods will prevail. Dispensing with these special measures is much easier than switching all price signals everywhere. Governments that want to discourage ISB merely need to leave architects, engineers, contractors, and developers alone and unsubsidized in any special *ad hoc* way.

If credit policy and institutions are wisely reformed to launch a major expansion of dwelling construction, a shortage of skilled workers and traditional materials may arise, together with demands for ISB as the only solution. Under these circumstances, government can be helpful in encouraging rapid training programs and the establishment of new plants for making bricks, blocks, and other materials.

Finally, the continual and timely development of urban transport systems, as well as the dispersion of employment centers within a metropolitan area, must be the responsibility of government. These policies will retard shortages of well-located urban sites and the pressure for high-rise building. If government planners concentrate their skills on metropolitan growth and finance, high-rise ISB is not likely to become a threat either to employment or to the quality of life. The precept to "love thy neighbor as thyself" was not, after all, dreamed up by anyone sharing the same building with a thousand fellow creatures.

7

Demand and Appropriate Building Technology

Introduction of less costly production methods can follow a change in income or asset distribution.[1] Long ago some writers argued that distribution should be *less* equal to encourage saving and the accumulation of capital for modern technology. Others held that mass production methods imply mass consumption, hence a *more* equal distribution of income.[2] Lately, the technology-distribution issue has surfaced again because of the claim that the rich consume goods that are more import intensive and less labor intensive than goods preferred by the poor. Specifically, the higher quality characteristics sought by the rich in their clothing, furniture, transportation, medicine, and entertainment are said to be made with more capital and imported components. If capital and foreign exchange were adequately priced, the problem would remain just distributional, not technological; but factor price disequilibrium is, of course, widespread in poor countries. Lack of economies of scale might in any case lead to a waste of both capital and labor in producing goods with characteristics sought only by the few.

For many products these issues of scale, labor intensity, and import characteristics have to be settled by empirical research, but in the case of housing, the evidence is already overwhelming. As Frances Stewart has put it:

> Consumption of rich country products *requires* an unequal income distribution in a much poorer country. Take the example of housing .... If [British] housing standards were adopted in India, with average incomes about one-twentieth of those in the UK, each person would need to spend £300 a year, which is more than the average income, on housing. Obviously this is impossible. There are two alternatives: modifying housing standards so that the cost of an average house... was around £200; or, providing £5,000 houses identical to those produced in the UK and allowing (or generating) sufficient inequality of income distribution to enable some of the population to ... be able to afford the £5,000 houses.[3]

E. Abebe has shown familiarity with the distributional constraint on technological choice.

> The choice of appropriate technology ... should be placed in the broader perspective of cost-benefit analysis. A full cost-benefit analysis considers all of the desirable and undesirable aspects of not only the available technologies but also of the type, quantity and prices of goods or services to be produced, the location and physical design, and the distribution of the project's expected monetary and non-monetary costs and benefits among different types of people in the society. The choice of technology should be made in close coordination with the choices or forecasts of these other aspects.[4]

If many low cost dwellings are built on inexpensive but well-located land that allows low-rise construction, a more labor-intensive technology can be used than if upper income groups were to be provided with high-rise apartments. Abebe concludes with the reminder that "the best way to expand employment in conventional housing construction is to increase the volume of construction through suitable mortgage credit and land distribution policies."[5]

These issues may be pursued in more detail. Policies which make mortgage credit and land more accessible to poor families are comparatively conservative. They do not redistribute current income but assets that, in the case of land, have not yet acquired their full value through the process of urbanization. Mortgage loans may divert capital assets to the poor only temporarily since they are to be amortized with newly generated savings. Certainly, such policies are less far-reaching than "correcting factor prices," meaning measures that affect income directly and that cannot be applied to one economic sector alone.

All these policy recommendations imply that planners for a better building technology must be concerned with more than just the design of blocks, beams, and patent laws. Changing the structure of demand for housing may be an unusually good opportunity for advancing an economy technologically. Not only is labor intensity and domestic production generated on the supply side, but also it is plausible that five new dwellings costing $2,000 will generate more benefits than one $10,000 house. Actually, land development and mortgage finance policies change the structure of demand only from the point of view of the construction industry. For the prospective occupants, the costs of land and finance are part of the supply price. The household's monthly payments go jointly for the structure, land, interest, insurance, and so forth. Owners often do not know what the cost breakdown is; and if construction prices fall while financial costs rise in proportion, they cannot acquire better lodgings. Raising the availability of land and finance is most critical for cheaper housing types because it may bring many households into the market that otherwise could not afford new housing at all. The problem is complicated by the durability of housing which makes any construction only a small addition to a large stock and which keeps old dwellings, possibly "filtered" or subdivided, as a major alternative. Informally built huts, often on illegal sites, are another alternative. The appropriateness of construction technology can be judged only in terms of its effect on use of the entire housing stock. This chapter will explore the matter in that context.

The Housing Stock

To simplify matters, the housing stock may be divided into six major dwelling types: luxury, good, low cost, minimal, substandard, and temporary. The dividing lines are somewhat arbitrary, but as may be seen in Table 22, the construction cost in each category (without land) is reported to be half that of dwellings in the next higher category and double that of dwellings in the next lower one. Dwellings in the lowest categories, temporary and substandard, are not built of permanent materials and lack adequate plumbing facilities. In the larger cities of developing countries, over half the population lives in such housing. The difference between these two types is that substandard dwellings are somewhat larger, have some access to piped water and sanitary waste disposal, and are generally good enough to allow further upgrading. I label these two housing types, H_0 and H_1.

Perhaps one-quarter of a population can live in the top three

Table 22. ***Characteristics of Major Housing Types***

	H_0, *temporary*	H_1, *substandard*	H_2, *minimal*	H_3, *low cost*	H_4, *good*	H_5, *luxury*
1. Typical construction cost without site, in 1970 dollars	$500	$1,000–$1,500	$2,000–$3,000	$4,000–$6,000	$8,000–$12,000	over $20,000
2. Number of rooms	1–2	2–3	2–3	3–4	5–8	6 or more
3. Materials	Rudimentary, refuse, adobe, sticks, mats	Adobe, and so forth. May be incomplete but improvable	Concrete blocks, bricks, usually incomplete and with inferior roofing	Bricks, blocks, reinforced concrete, and other modern materials	Modern materials	Modern materials
4. Plumbing	No modern water supply or sanitary waste disposal	Communal facilities nearby or rudimentary indoor water and waste disposal	Inside water and waste disposal but no complete bathroom	All utilities, including a fully-equipped bathroom	All utilities, including a fully-equipped bathroom	All utilities, several bathrooms
5. Availability of mortgage credit	None	Rare	Some public	Mixed public and private	Mostly private	Private

SOURCE: Christian Araud, Gerard Boon, W. Paul Strassmann, and Victor Urquidi, *Studies on Employment in the Mexican Housing Industry* (Paris: OECD, 1973); Ridha Ferchiou, "New Construction, Subsidies, and Filtering of Dwellings in Tunisia: A Vacancy Chain and Linear Programming Analysis," Ph.D. diss., Michigan State University, 1975; Jesus Yáñez Orviz, "Optimal Allocation of Housing Investment in Five Mexican Cities, 1960–1970, 1970–1980," Ph.D. diss., Michigan State University, 1976; Orville F. Grimes, *Housing for Low-Income Urban Families* (Baltimore: Johns Hopkins University Press, 1976); United Nations, *A Global Review of Human Settlements and Statistical Annex* (New York: 1976); and the following by W. Paul Strassmann: "The Construction Sector in Economic Development," *Scottish Journal of Political Economy* 17 (November 1970): 391–409, *Conventional Technology, Construction Wages, and Employment* (Geneva: World Employment Program, ILO, 1974), and *Employment Generation through Residential Construction in Rio de Janeiro* (Washington, D.C.: Agency for International Development, 1975).

categories — low cost, good, and luxury, or H_3, H_4, and H_5. These are the only types that are solidly constructed according to modern standards and have all utilities, including a fully-equipped bathroom. Overambitious building codes have usually permitted nothing less and have aggravated housing shortages. So-called low cost (H_3) housing has often been rationed out to government workers or other employees of the modern sector at heavily subsidized rates. Some of this housing is later subdivided among lodgers, and much of the rest is filtered upward to high income groups.

Michael Cohen has observed the phenomenon in the Ivory Coast:

> High quality housing, building standards, capital intensive infrastructure . . . all reflect official intentions to develop urban areas according to ultramodern standards.
>
> In many cases, individuals in Abidjan have not applied for construction permits because they know they could not meet the high-cost construction standards required for the permits . . . . The Minister of Construction and Town-Planning [in May 1963] coined the slogan "Construct beautiful, big, and forever!"
>
> Although some credit is given for urban housing, it is usually reserved for people having high salary levels . . . . The result is a serious housing shortage and the development of vast bidonvilles . . . which totally contradict the official emphasis on the maintenance of standards. Lacking roads, water, electricity, and sanitation facilities, the bidonvilles house more than half the city's population.[6]

Sharply rising rents soon made middle income families complain and led the government to modify its policy somewhat in 1970. Low cost housing of the H_3 type was given public financial support, but land was provided by razing the vast bidonville of Port Bouet.[7] Similar examples can be found throughout the world.

The intermediate category of H_2 housing can be supplied in part by encouraging the upgrading of H_1 substandard housing with small loans. Otherwise, various types of subdivided dwellings as well as "core housing" belong in this category. The "core" is a modern shell with incomplete indoor plumbing facilities, designed in a way that allows improvement and expansion by the occupant. This type of housing has been the subject of some technological research, but much remains to be done.

A stock-user matrix relates a stock of dwellings to a population of households. In Table 23, an illustrative matrix, the household categories F_0, F_1 . . . F_5 have income boundaries that match the six dwelling categories that have just been described. In order to afford a

Table 23. *Stock-User Matrix for a Hypothetical Poor City of 100,000 Household in Initial Year*

Dwellings, average value / Monthly household income	Number of household-dwelling combinations H_0 \$633 (\$363)	H_1 \$1,266 (\$844)	H_2 \$2,531 (\$1,969)	H_3 \$5,063 (\$4,568)	H_4 \$10,125 (\$10,620)	H_5 \$23,625 (\$28,875)	ΣF	Index
F_0 \$50 or less	20,475						20,475	—
F_1 \$51–\$100	8,234	16,469					24,703	83
F_2 \$101–\$200		8,234	16,469				24,703	83
F_3 \$201–\$400			4,813	9,626			14,439	83
F_4 \$401–\$800				2,402	4,805		7,207	83
F_5 Over \$800					2,824	5,649	8,473	83
ΣH	28,709	24,703	21,802	12,028	7,629	5,649	100,000	83
Remaining H after 15 years	—	14,414	12,418	8,207	6,041	5,061		
Annual rate of replacement, in percentage	—	2.0	2.0	1.5	1.0	0.5		

NOTE: A modal income of \$100 monthly (or double the minimum wage) is assumed. Income is lognormally distributed, with each range in the table equal to .75 of a standard deviation. Beyond two standard deviations from the mode, a Pareto tail adds 9 percent of the total number of households to that part of the range. M/Y, the share of monthly payments in personal disposable income paid for housing, is .225. H_j values given in parentheses reflect an income elasticity of demand of 1.33: M/Y rises from .13 to .275. Value of the dwelling without the site equals 75 monthly payments. One-third of households spend less than this desired level.

Aggregate personal disposable income was \$322,128,000 in the initial year. If this amount was 78 percent of Gross City Product (GCP), \$412,986,000 was the level of GCP. For this percentage, see Simon Kuznets, *Modern Economic Growth: Rate, Structure, and Spread* (New Haven: Yale University Press, 1966), p. 406.

$10,000, good, H_4 dwelling, monthly income should be between $400 and $800. If income were in the middle of the category, or $600, and if 22.5 percent were spent on housing, monthly payments would be $135. One hundred of these, or $13,500, would be a typical value of house and lot that could be financed thereby. The site can easily account for one-quarter of the total, leaving $10,125.

Let us say that a monthly income of $50 corresponds to the minimum wage. Any household earning less than this must double up with another or live in a rudimentary H_0 shack worth perhaps $500 of "sweat equity." If housing were available so that each household could occupy the type of dwelling that it is willing and able to finance, all the numbers in Table 23 will be on the diagonal: F_1 families will live in H_1 housing; F_2 families in H_2 housing; and so on.

Usually, lack of land and lack of finance plus population growth and demolition have caused a shortage of housing, so that families get less housing than they would normally be willing to pay for. For example, an F_4 family must crowd into an H_3 dwelling, while bidding up its price or rent. Many numbers in Table 23 (the stock-user matrix) will be in squares to the left of the diagonal.

In the hypothetical case of Table 23, one-third of the 7.2 percent of families with monthly incomes between $400 and $800 are living in $5,000 not $10,000 dwellings. Converted to index numbers, two-thirds are in houses rated as 100, and one-third in houses rated only 50. The weighted index is 83. The same shortage is assumed to exist for all other income groups (except those already in the most rudimentary shacks because of poverty), which makes the overall index also 83.

If this number of households and dwellings were to remain unchanged, the policy question would be to select an income group to move first from 83 to 100. An income group that moves *beyond* 100 with new dwellings would have to be subsidized in the short run, and if shortages persist in higher income groups, the chances are that the dwelling would eventually be traded up. In fact, such upward filtering is likely whenever any richer family occupies a dwelling worse than that occupied by some poorer family. Housing agencies have difficulty in controlling who lives where some years after a dwelling has been built. Through control over mortgage finance and land development, they can mainly decide what type of structure is built, other than substandard units, shacks, and mansions, and who will be the first occupants. Indeed, slow land development and inadequate mortgage finance are the main factors that have kept households in inappropriate dwellings with a rating of less than 100. After all, the appropriate

100-level dwelling was *defined* as one that a household would be willing to pay for over time.

In determining the priority recipients of new dwellings, housing agencies are most likely to go by custom, political influence, convenience, or conservative standards of finance. More forward-looking planners would recommend the housing categories that will allow use of a nationally more appropriate technology and raise national housing welfare the most. Although given the investment, the yield may be somewhat lower, improving the housing of five poor families will be preferred to improving that of one rich family.[8]

Looking Fifteen Years Ahead

The main point is that the decision cannot be made that simply. Whatever housing is built will be around for decades, and in the meantime the rest of the housing stock deteriorates, construction continues year after year, the population grows, and household incomes rise in the course of development. The optimal and technologically appropriate investment can only be decided in the context of a changing total housing stock used by a changing set of occupants. If this technology is promoted by assigning certain housing types priority, where will our cities be in fifteen years? Will the index of housing welfare have risen as close to 100 as possible, given other national investment priorities?

The way to solve the problem is to consider the entire planning period as a unit. When it is over, how much of the current housing stock will be left? What is the total amount of dwelling construction that the country or city can afford, excluding shacks and substandard units that are beyond control? What will be the rate of population growth and migration? At what rate will productivity rise and income distribution change? In short, how many families will be in the different original income categories in fifteen years? Most of these questions can be answered in a reasonable manner, and therefore one can tackle the overall problem of choice of dwelling type and technology.

With respect to the deterioration of the housing stock, one has to determine the life expectancy and current age of different dwelling types. If the life expectancy of good (H_4) housing is thirty years, and if this part of the stock has been growing at 4 percent annually before the initial year, we know that one percent must be replaced annually. In the example of Table 23, we see that of the initial 7,629 H_4 units, only 6,041 will remain after fifteen years. Similar estimates can be made for the other housing types. Of the original 71,300 dwellings other than 28,700 temporary ones, only 46,100 will remain, or 65 percent. A sophisticated estimate would modify this forecast by the expected rate of upgrading and subdivision.

Projections of population growth and migration have been made for most cities throughout the world. More difficult is a forecast of income growth and distribution. One can either work with separate estimates for different groups within the population or with an overall pattern. For example, one might estimate that there will be a higher influx of poor people from the countryside and that, once in the city, income growth of the migrants will be higher (or lower) than that of others. Alternatively, one can project the median or modal income of the city and assume that the distribution around that value will remain unchanged. If one-third of households were within one standard deviation from the median before, one can assume that one-third will still be there. But after fifteen years the median will be higher, and the number of households will be one-third of a much higher total.

The example shown in Table 24 illustrates the second or overall approach. At a 4.5 percent annual growth rate, the 100,000 households of the initial year (Table 22) will have proliferated to 193,500 by year 15. Modal monthly income has grown from $100 at a 4 percent annual rate to $180 monthly. GDP per capita has risen from $826 annually to $1,488. The share of households in the poorest two income categories has fallen from 45 percent to 23 percent, but their absolute number has hardly changed, from 45,200 to 44,900. Meanwhile, the share of households in the two highest income levels has risen from 16 percent to 28.5 percent, or more than tripled, from 15,700 to 55,200. Since housing is durable, construction plans must anticipate such changing distributions.

Investment Priorities

The last item that must be estimated before distributional and technological policy can be set is the investment constraint. What volume of resources can be devoted to housing during the fifteen-year period? Ideally, this amount will be set within a framework of a macroeconomic policy that also considers the needs of agriculture, transportation, manufacturing (especially export industries), the chances for foreign loans, and so forth. Presumably, a share of GNP for housing will be deduced and that share will be further divided among different cities and the countryside. To simplify matters, the share can

Table 24. ***Stock-User Matrix for the Poor City after Fifteen Years of Uniform Growth and Optimal Allocation of 4.5 Percent of Gross City Product to Housing Construction without Subsidies to Any Group***

Households	*Number of household-dwelling combinations*							
	Dwellings						ΣF	*Index*
	H_0	H_1	H_2	H_3	H_4	H_5		
F_0	7,380	14,420					21,800	—
F_1		10,720	12,420				23,140	154
F_2			47,810				47,810	100
F_3				45,600			45,600	100
F_4				26,000	—		26,000	50
F_5				10,100	14,040	5,040	29,180	50
ΣH	7,380	25,140	60,230	81,700	14,040	5,040	193,530	91
Remaining H_j		14,420	12,420	8,270	6,010	5,040		
							ΣD	
Build, D_j		10,720	47,810	73,430	8,030	—	139,990	

NOTE: Assumptions are that the number of households grows at an annual 4.5 percent and income per household at an annual 4 percent at all levels. Income elasticity of the demand for housing is 1.00.

be aggregated over the fifteen-year period and taken as a lump-sum constraint. Perhaps one can exclude the richest and poorest households who will build with their own independent resources, but for everyone else this much can be built and no more. What allocation will yield the most welfare and the best technology?

Let us go back to our hypothetical city. If its fund for housing is set at 4.5 percent of gross *city* product, a rather typical amount, the total available over 15 years will be $588 million. If all of this goes into low cost H_3 housing at $5,000 each, only 118,000 units can be built, leaving a deficit of 29,000 units. The number of F_3 families with about $300 in monthly incomes that could reach an index of 100 with H_3 housing will be only 45,600, and 8,300 of these could occupy old H_3 dwellings. Whatever the optimal solution may be, this is not it.

If the entire $588 million were spent on core houses, about 235,000 units could be built. These are far too many: 88,000 more than the total housing deficit. The ideal allocation (without subsidies to any group) is illustrated below.

Housing category	*Number to be built*	*Cost (millions of dollars)*
Good (H_4)	8,030	$ 81.3
Low cost (H_3)	73,430	$371.8
Minimal (H_2)	47,810	$121.0
Substandard (H_1)	10,720	$ 13.6
Total	139,990	$587.7

The effect of building this combination is shown in Table 24. No other way of allocating the $588 million will improve housing welfare more, or raise the aggregate weighted index as high as 91, or bring more households to the diagonal of the matrix into appropriate housing. The solution was obtained through a linear programming method that I have described elsewhere.[9] In this instance, no luxury building is allowed, and most of the rich must be content with merely good or low cost housing. As Table 24 shows, all F_2 and F_3 households with monthly incomes between $100 and $400 will be appropriately housed in H_2 and H_3 dwellings. In fact, so many minimal or core (H_2) dwellings are built that all old units of this type can be filtered down to F_1 families as the price falls. These F_1 families are now living in dwellings better than what could be newly built for them without loss or subsidy. The weighted index of housing welfare for this group, therefore, rises to

154. The substandard units in which a part of this group still lives are the result of a $13.6 million loan, perhaps in the form of sites and services development. The 14,400 former substandard units inhabited by F_1 families can be sold or abandoned to the poorest F_0 households that are beyond the reach of unsubsidized housing support. Our method of solving the allocation problem has necessarily been so devised that the benefit from both construction and subsequent filtering, that is, redistribution of the entire housing stock through the market, is taken into account. Otherwise, this way of disposing of the $588 million would not raise the index of housing welfare the most.

Obviously, the example is optimal only within the stated assumptions. Proponents of housing can demand a larger share of gross city product for housing than 4.5 percent. They can insist that, because of the many externalities from housing, poor families should be subsidized so that their housing will be "above the diagonal," or better than the poor would choose with existing incomes. Such measures do not seem exorbitantly expensive. To give the remaining 7,400 homeless families serviced sites at $1,300 each would take only 0.2 percent of gross city product over the fifteen-year period in our hypothetical city. Even if all the 44,000 F_0 and F_1 families existing in the fifteenth year were placed in $2,500 core housing ($H_2$), with partial subsidies where needed, the cost would be only $118 million in subsidies, or 0.9 percent of the aggregate fifteen-year gross city product.

Conclusion

The point of the numerical example was not to make preliminary estimates that will be valid throughout the world. The level and growth rate of income can vary widely, as can its distribution and the growth rate of population. The priority assigned to housing and institutional constraints on building will hardly be uniform among countries. What the example was supposed to show is that these different elements can be brought together in a simple and coherent framework for assessing trends over the kind of planning horizon that a durable commodity such as housing demands. Elaboration of the framework to allow for upgrading, subdivision, alternative locations, and variations in family structure will be valuable if data on these matters are to be collected. But even the simple version demonstrated here is better than the crude projections of "housing gaps" that predominate today. If population is not projected by income category, and if the shifting around of the housing stock is ignored, we are likely to build the wrong type of housing — too cheap or too expensive.

When the volume and composition of housing demand are inappropriate, then innovations in design, construction methods, and materials are likely to be similarly inappropriate, although perhaps not to a corresponding extent. Some innovations do not depend on volume or quality requirements, but others do. If proper land development and mortgage finance policies do not bring out the latent demand for a particular housing type, the related innovations cannot come into their own. By the time a country reaches the level where per capita product in major cities reaches $800 (or perhaps $500 nationally), the primary need is likely to be H_2 minimal or core housing. We probably know less about fostering this type of building than any other. If a substantial volume of such housing brings out major technological improvements in quality or reductions in cost, not only will millions of people benefit, but also a feedback effect will change stock-user matrix projections. Durability may rise and allow more of that type of housing to survive. Rising quality per unit of cost may change the income elasticity of demand for housing. Insofar as changes can be foreseen, one can estimate to what extent they will improve housing welfare by moving the population closer to the matrix diagonal. One can compare the cost of alternative ways of improving housing welfare with the net improvement that results.

Thus we see that appropriate choice of technology depends partly on an appropriate distributional policy that assigns priorities for the acquisition of newly developed land and newly formed capital. One can go further by redistributing income through subsidies and other means, but in housing much can be done without going far in that direction. In any event, how far one should go depends partly on the claims of other economic sectors. Although the supply of building materials, trained workers, and skilled entrepreneurs may seem highly elastic in some countries, as much cannot be said for the supply of all the products for which an expanded building program employing many workers would generate demand. Hence, housing construction may be limited to some share of gross national product by macroeconomic considerations. The type of housing policy model recommended here shows a way of coping with that type of constraint and explains its relation to the housing types that should have priority.[10]

8

Employment and Technology in Building: Conclusions

Building technology is a complex field, and many issues are not covered in this book. Concentration had to focus on one important effect of technology: employment changes. Do owners, architects, builders, and artisans in developing countries choose techniques that take full advantage of the available labor force? What employment options does the conventional technology offer? How much of a price or wage change is needed before one switches from one method to another? Will rapid wage increases, on balance, help or harm the labor force?

One may expect future innovations to be similar to those of the past decade or two, or at least to reflect research begun during that period. So the book considers the origins of labor-saving and employment-generating innovations. Is public support for innovation needed? Does the application of science destroy jobs? Could poor countries benefit from the most radical innovations in rich ones? What is the chance for preserving employment by the better use of indigenous materials or by improving organization on both the supply and the demand side.

If not enough has been found to give definitive answers to each of these questions, that may be an understandable shame, but not to suggest a few admonitions after so many pages would be improper. This book and its closing admonitions are, therefore, about two kinds of technology that should be used fully, but not in a way to destroy employment: (1) conventional technology and (2) unconventional technology.

Perennial Elasticities

Since conventional technology is more widely used than anything else and seems very durable, almost perennial, an important chapter was devoted to conventional alternatives. If an identical building component could be installed with several well-known methods using different amounts of labor, anyone concerned with employment must know how these building methods are chosen.

Most likely, builders will choose the cheapest method. Their choice depends on the relative amounts of labor, materials, and equipment required by each method and on the wage or price per unit. If the wage of plasterers rises compared with the price of more quickly applied plaster or plastering equipment, fewer plasterers will eventually be hired and more will be spent on equipment and materials. For building as a whole, the labor/materials-equipment ratio will fall as the wage/nonlabor-price ratio rises. The relation between that fall and rise, both expressed in percentages, is the elasticity of substitution, and much (possibly undue) space was given to its estimation.

A critical level of the elasticity is unity. At this point the amount paid per worker rises exactly as employment falls (relative to other inputs), so that the share received by labor is unchanged. With a lower elasticity, employment falls less, and the share rises; with an elasticity above unity, employment falls more, as does the wages share.

Elasticities were estimated individually and collectively for a set of nineteen countries — eight less developed, five intermediate, and six advanced. Data had to be used for the construction sector as a whole, including other building and public works. The best estimate for the cross-section was .86. For a subset of seven high growth countries, the average of individual elasticities was 1.05. For five advanced European countries, it was 1.32. Over a period of 17 years, the Mexican elasticity was 1.38, and the share of wages in construction output fell from 38 to 27 percent.

These estimates apply to construction as a whole, and wage policy for the sector should not ignore them. A possibility exists, however, that the technological elasticity is lower and that the relative fall in employment is due to a shift in demand to less labor-intensive structures. This possibility could be examined in detail for housing and be partly confirmed.

At first glance, it appeared to be false because a one-third share of labor in the sum of on-site wages and materials seemed to fit the circumstances in Africa, Asia, Latin America, and more developed countries, especially for single family housing. Only the Middle East and North Africa were generally higher. Low productivity during rapid expansion seemed to be a factor in that region.

A closer look at housing costs nevertheless shows that more developed countries choose less labor-intensive housing. Higher quality housing incorporates more expensive materials and equipment, which automatically lowers the share of on-site labor even if employment and wages remain unchanged. Moreover, development means urbanization and multistory apartments in larger cities; comparing structures with one story to those with four to eight, the share of on-site wages in structural cost falls from 29 to 26 to 24 percent (in conventional Colombian and Mexican building). Superficial statistical analysis would attribute the fall exclusively to rising wages and an elasticity far above unity; in fact, both changes are partly the result of development as a whole. A substitution elasticity around unity threatens sufficient unemployment.

The goal of a policy promoting employment is not only to raise on-site construction work but also *any* kind of remunerative employment. Hence, the indirect labor content of materials and equipment has to be seen as offsetting lower on-site employment. Estimating the labor in the materials, and the materials that go into the materials, *ad infinitum,* is an elaborate statistical procedure; thus far, studies exist only for Brazil, Mexico, and the United States, although others are under way elsewhere. In Mexico around 1970 the indirect labor content was about 35 percent of all man-years in a single family house (without off-site construction work, urbanization, and sales); in the United States it was 55 percent. In Mexican low cost housing, the indirect labor share was only around 30 percent, but for luxury housing it rose to 40 percent. For apartments, the percentage was a few points higher, especially for high-rises.

But the rise in indirect employment does not offset the fall in on-site employment. In Mexico, indirect labor costs rose only from 13 to 16 percent of structural cost as quality changed from low cost to luxury, while direct labor costs fell from 32 to 20 percent: a net loss of 9 percent (from 45 to 36 percent).

The Moment of Truth: Wages Policy

The policy conclusion that may be drawn from this rather mixed evidence must be comparably mixed. A decline in the wages share of building and a fall in the growth rate of construction employment should not immediately provoke a policy of lowering real construction wages, perhaps by letting them lag behind inflation. The falling wages share may be due to a shift in the composition of output — higher quality and higher rise dwellings that may be desired or inevitable. They may reflect urbanization and a rising middle class. If the shift in composition is undesired, a change in mortgage credit policy might reverse it and restore the labor intensity of building as well. Whether or not employment is thereby restored depends on whether or not the volume of building falls by a critical amount with the shift to labor-intensive dwellings.

If there is no shift in composition, one still has no case for a restrictive wage policy simply because substitution is occurring. Labor costs may be high because of inefficiency as much as high wages. Training of workers and managers must therefore keep up with, and even anticipate, rises in construction demand. Such demand is likely to accelerate at the middle income level of economic development, together with urbanization and the need for infrastructure. The sensible vogue for seeing construction as a leading sector — given disappointment with agriculture and manufacturing — will contribute to this pressure. Mechanization because of failure to expand training programs should not negate the very employment-generating characteristics that originally helped make construction an appealing sector.

The existence of strong construction unions and legislation about minimum wages and fringe benefits also does not constitute *prima facie* evidence that labor costs are too high and that substitution is causing unemployment. The best evidence of that is a pool of manpower capable of doing construction work but jobless. If such a pool exists, as is often the case, any elasticity above unity means that the higher earnings of the employed make workers as a group worse off, that the gains of some do not match the losses of the unemployed. Where good employment opportunities do not exist elsewhere in an economy, the brutal fact is that even fairly low wages can be too high. Where the elasticity is unity or a little below, at least the gains of the employed are not less than the losses of the jobless in monetary — although not psychological — terms.

One important theme of this study is thus that conventional technology, with its vast variety of substitution possibilities, harbors threats to employment and the welfare of workers if training programs are inadequate and if there is undue interference with labor markets through raising wages prematurely. But that is not the only kind of intervention, nor the only kind of technology, hence not the only theme of this study. In addition to conventional technology, novelties can be promoted or retarded.

Ingredients of Innovations

Through a survey of the literature, personal correspondence, and fieldwork interviews, a large sample of innovations of the past two decades was selected and a subset of sixty-five was analyzed statistically. It was found that private firms are fully capable of importing the rather humdrum off-shelf innovations that do not require further local adaptation or research. The more creative changes that improve organization or perfect traditional methods, and that might depend on substantial scientific research, are strongly associated with public agencies, such as building research stations and productivity centers. It was demonstrated that these innovations are not remarkably complex, and since complexity is associated with risk, one might tentatively hold that they are not riskier than less creative means. Perhaps they only seem complex and risky to the less well informed in the private sector.

One benefit of the more public, science-based research is its tendency to lower material costs, while all other innovation types mainly reduce labor costs. *Science-dependent* innovations are good at developing new uses for indigenous materials or adaptions to fit local peculiarities, such as foundation types. By definition, *off-shelf* innovations cannot achieve anything of the sort, but since these are inexpensive and involve little risk in the narrow sense, it would be foolish to discourage this way of bringing in useful advances that might have been heavily science-dependent abroad.

On the other hand, *off-shelf* innovations and those that *adapt advanced* methods from abroad with little reference to local materials should not be encouraged with special licenses and subsidies. These innovation types, unlike all others, are likely to increase equipment cost and be capital intensive. Unfortunately, public support, including research and special subsidies, has often vainly tried to adapt unsuitable advanced methods. The most flagrant case is that of prefabricated industrialized systems building, referred to here as ISB.

An Evergreen Fantasy

To oppose advanced systems of prefabrication for walls and floors under all circumstances would be wrong. For schools, hospitals, office buildings, and apartments in advanced countries, ISB has been logical and successful. Modular coordination and prefabrication of many components will always be desirable. But ISB is not optimal for all circumstances, specifically those of developing countries.

With a five-year volume of 1,500 to 2,000 dwelling units in apartments of four to five stories at one site, the best ISB technology theoretically could match the cost range of conventional low cost housing of $35–$45 (in 1970 dollars) per square meter. No more than 3 percent of on-site jobs would be lost, or 100 man-years.

That is the most that can be hoped for in developing countries. The vast majority of systems need a much larger volume, far exceed conventional costs, and displace hundreds of additional workers. Although two decades of failures with such systems in developing countries have passed, governments come and go, memory fades, and salesmanship persists; ISB again and again comes in for another try.

The misleading appeal of ISB has many facets. One is human fascination with anything neat and systematic that seems to replace chaos. Another is that speed of construction per dwelling unit is easily confused with cost or with the annual rate of building that a country can afford. A saving of six months of construction time should be rated as worth no more than about 6 percent of the price of a dwelling. Nothing in an abstract formulation of a building system gives a clue to inexperienced policy makers about start-up delays, on-site interruptions, breakage rates, and other problems that arise in practice.

The lengthy chapter 6 and Appendices C and D, detailing Colombian and Puerto Rican experience, have attempted to dispel these illusions. The claim that ISB has desirable quality features is denied. Costs and difficulties with transporting, lifting, and placing heavy components are given in detail. Examples show how failure to reach the minimum volume can double costs per square meter. On the other hand, costs cannot fall much; ISB mainly affects the building shell, which only accounts for one-third of conventional construction costs, the rest being foundations, fixtures, and finishing.

A long section contradicts the claim that ISB is justified by savings of land or rising density. In fact, not much land is saved by shifting from a net density of 200 to 400 dwellings per hectare. Per floor, ten-story as compared to four-story buildings save only one-eighth as much land as does shifting from two to four stories. Furthermore, four-story dwellings are built more cheaply, with conventional bricks, blocks, or *in situ* pouring of concrete, than with ISB techniques. Because of the need for better foundations, more structural support, and more elevators and equipment, high-rises as compared with four-story buildings cost about 25 percent more per dwelling in advanced countries, 50 percent more in Latin America, and 100 percent more in India. Even including the extra land needed at extravagant prices of US$70 per square meter, conventional four-story apartments remain much cheaper than high-rises. From the viewpoint of saving land for agriculture, recreation, or wildlife, the greater densities of high-rises would release only about one-tenth of the land that would otherwise be urbanized.

Since examples are often more persuasive than logic, the study has shown how the European countries that have pioneered high-rise ISB for apartments have lowered its share from about 45 to 20 percent of new dwellings. Moreover, the belief that the Industrial Revolution has somehow left conventional building untouched has been shown to be false. What else can one say?

Hazardous but Not Invariably Fatal Technological Victories

Industrialized systems building in various forms is not the only example of *adapting advanced* technology to developing countries. Reinforced ceiling beams are a kind of prefabrication that complements traditional methods. The same applies to wood preservation methods and a variety of block and brickmaking machines, some operated by hand. Innovations involving woodchips, formwork, and foundation piles also belong in this category. About two-thirds of the innovations in the sample claimed to be labor saving, but for only one-third was this characteristic the only presumed cost reduction.

Purely *off-shelf* innovations with negligible adaptation were tubular scaffolding; mechanical plastering equipment; some types of formwork; integral terrazzo floors; asbestos cement pipes; sand-lime and lightweight bricks; various components made of PVC material, such as pipes, floor tiles, window frames, and even wallpaper, and all sorts of simple mechanical devices. For half the *off-shelf* innovations surveyed, labor saving played a part. Unlike ISB, most of the innovations were relatively simple and usually needed no substantial minimum volume of dwellings at a site for success. *Off-shelf* innovations border on being an alternative within conventional technology; they merely differ in having come newly from abroad during the period considered.

One hears about *improving traditional* technology as the best route for developing countries, but only a few innovations fit exclusively into this category. Fireproofed thatch roofs and stabilized soil bricks are clear examples. A loom for weaving sago palm wall matting in New Guinea is another. It improves quality and lowers cost compared with handmade matting and replaces eight skilled workers with one unskilled man. But the innovation keeps the matting competitive with even less labor-intensive hardboards, asbestos sheets, and galvanized iron.

Science-dependent innovations are those that adapt the advanced or improve the traditional more profoundly by analyzing the properties of materials, soils, and structures. Such innovating often takes as point of departure some indigenous raw material or waste product. There are possibilities in rice husks, cashew nut shells, sisal, ashes, and particularly poor soils. Sulfur can be combined with fiberglass, or bamboo with polyurethane. Much research on insulation, seismic stability, and hurricane resistance belongs in this category. A successful example is the solar water heater, already widely used in countries with Mediterranean climates.

Only one-third of the *science-dependent* innovations examined here appear markedly labor saving or dependent on a large volume at a site (economies of scale) for success. Two-thirds are material saving, as already mentioned, their principal characteristic. There does seem to be a tendency to confuse technical victories with economic success. Not every process that gives a worthless substance valuable characteristics on the laboratory bench can do the same on a competitive industrial basis. Even successful *science-dependent* innovating takes a long time and may be suspected of failure by outsiders during the gestation process. Most building research institutes would therefore be wise to continue with off-shelf dissemination, modest adaptation, and fostering of better organization.

Organizational changes, paradoxically, reduce and therefore preserve the labor intensity of efficient building methods. It appears that half of labor time usually is spent on activities that do not make the building grow. A capital-intensive method that halves the labor force eliminates 50 percent of both productive and paid-for but wasted time. *Organizational* innovations are intended to eliminate wasted time without recourse to capital expenditures. Some organizational changes may be inherent in simple adapted tools, such as the trowels developed in India. Others are inherent to a change in design, such as the cavity wall with vertically set bricks tested in Madras. Organizational changes range from job studies to altering the sequence of operations, rationalization, modular coordination, quality control, proper testing of materials, and building code reform. Some of these save materials cost as well as labor. The area of organizational improvements seems to have been neglected in developing countries. Apparently, it is easier to adopt something tangible that does not call for subtle changes in behavior. Yet, intangible changes are less risky since attempts to improve organization seldom cost much and rarely fail. Thought and behavior have to change a bit, which can lead to different roles and identities, and for rigidly traditional bosses and craftsmen, an embarrassing feeling arises of having lost one's soul. Historically, that has always been the real price of economic development.

Time, Wishful Thinking, and the Ultra-Appropriate: A Summary

Conventional building technology allows labor to be replaced in a wide variety of ways. The elasticity of substitution is probably not far from unity. In the long run that substitutability, doing with less labor, is good because economic development makes human time monetarily what it always was philosophically — more valuable than anything else. Time should be used sparsely, yet richer people need more shelter to enclose their more varied leisure-time activities. So substitution in building methods is necessary.

A premature monetary push on building wages may, however, defeat the purpose and give workers time to be philosophical without income. Substitution will come soon enough without being rushed.

Cost-reducing innovations may also lower man-hours per unit. Since competition is typical in construction, prices should fall with cost, and given elastic demand, a rise in employment should follow. One mainly has to be sure that innovations are not promoted with wrongly priced components and wishful thinking about keeping volume at a site above, and breakdowns below, a minimum.

Whether they are copies, improvements, adaptations, or drastic reorganizations, the best cost-reducing, quality-raising innovations should be welcome. If they produce cheaper, safer, more convenient, and more attractive dwellings, they are appropriate technology. But even ultra-appropriate innovations will be more effective if they are part of an appropriate housing sector strategy. The greatest barrier to improving the housing stock is not inability to design better dwellings and construction methods, but clumsy housing sector institutions.

Appendix A

Housing Levels and Employment in Mexico

Housing Levels and Employment in Mexico

A study of employment and housing levels in Mexico was carried on during 1970 – 1972 by the Colegio de Mexico, sponsored by the OECD Development Centre, the Inter-American Development Bank, the World Bank, and the Ford Foundation. Housing levels were studied in both senses of the word — levels of stories and levels of value. Low levels in both senses were found to be more labor intensive. This appendix will not reproduce every finding of a long and complex study, but for useful comparisons it may be helpful to bring salient facts together in consolidated tables with figures converted to 1970 dollars.[1]

The analysis began with 48 typical floor plans grouped into eight categories of housing, half single and half multifamily dwellings. Average physical requirements for excavation, foundations, walls, windows, and so forth, were determined for each of the eight categories. Direct labor requirements were taken from a standard handbook. The labor content of materials was established in two steps. First, the employment ratios were found for the main materials from the industrial census. Second, labor in minor materials and the labor content of the material inputs into the major materials were found by constructing a final demand vector for each housing type and using an inverted interindustry matrix.

Table A1. ***Man-Years and Costs in Mexican Single Family Housing, 1970***

	Minimal	*Low cost*	*Good*	*Luxury*
1. Area of dwelling, square meters	47.3	63.6	163.8	384.4
2. Structural cost, dwelling without site, 1970 U.S. dollars	$1,035	$2,576	$8,924	$28,830
3. Cost per square meter, 1970 U.S. dollars	$21.88	$40.36	$58.48	$75.00
4. Man-years pei dwelling	.51	1.22	3.98	12.57
5. Construction (and percentage of 4)	.36 (70.6)	.84 (68.9)	2.61 (65.6)	7.45 (59.3)
6. Onsite	.31 (60.8)	.73 (59.8)	2.23 (56.0)	6.21 (49.4)
7. Unskilled	.15 (29.4)	.33 (27.0)	1.20 (30.2)	3.34 (26.6)
8. Skilled	.16 (31.4)	.40 (32.8)	1.03 (25.9)	2.87 (22.8)
9. Offsite	.05 (9.8)	.11 (9.0)	.38 (9.6)	1.24 (9.9)
10. Indirect	.15 (29.4)	.38 (31.1)	1.37 (34.4)	5.12 (40.7)
11. Man-years urbanization (and percentage of 4)	.08 (15.7)	.10 (8.2)	.20 (5.0)	.62 (4.9)
12. Construction	.06	.06	.13	.38
13. Indirect	.02	.04	.07	.24
14. Man-years dwelling and urbanization	.59	1.32	4.18	13.19

15. Man-years promotion and sales	.02	.05	.27	1.08
16. Total man-years	.61	1.37	4.45	14.27
17. Labor earnings, construction and indirect, dwelling only, 1970 U.S. dollars	$455	$1,109	$3,768	$10,930
18. Share (of 17) in structural cost, percentage	44.0	45.1	42.2	37.9
19. Construction labor earnings	31.9	29.7	28.0	22.4
20. Indirect labor earnings	12.1	13.4	14.2	15.5
21. Materials costs, 1970 U.S. dollars	$591	$1,542	$5,489	$19,306
22. Share in dwelling cost, percentage	57.1	59.9	61.5	67.0
23. Share: Onsite labor costs to sum of onsite labor and materials percentage	35.7	33.7	31.8	25.7

SOURCE: Data collected by Christian Araud and Santiago Rincón Gallardo, some of which is given in Christian Araud, Gerard Boon, Victor Urquidi, and Paul Strassmann, *Studies on Employment in the Mexican Housing Industry*, Development Center Studies, Employment Series No. 10 (Paris: OECD, 1973), especially pp. 80, 163. It was assumed that offsite construction labor is paid at double the rate of onsite labor. Other figures are empirical.

Table A2. ***Man-Years and Costs in Mexican Multifamily Housing, 1970***

	Low cost 4–5 stories	*Good 4–5 stories*	*Good over 5 stories*	*Luxury 8 stories*
1. Area of dwelling, square meters	67.3	89.7	89.7	112.1
2. Structural cost, dwelling without site, 1970 U.S. dollars	$2,875	$5,018	$6,368	$9,161
3. Cost per square meter, 1970 U.S. dollars	$42.72	$55.94	$70.99	$81.72
4. Man-years per dwelling	1.41	2.36	2.37	4.03
5. Construction (and percentage of 4)	1.01 (71.6)	1.49 (63.1)	1.61 (67.9)	2.34 (58.1)
6. Onsite	.89 (63.1)	1.27 (53.8)	1.33 (56.1)	1.85 (45.9)
7. Unskilled	.41 (29.1)	.59 (25.0)	.67 (28.3)	.82 (20.3)
8. Skilled	.48 (34.0)	.68 (28.8)	.66 (27.8)	1.03 (25.6)
9. Offsite	.12 (8.5)	.22 (9.3)	.28 (11.8)	.49 (12.2)
10. Indirect	.40 (28.4)	.87 (36.9)	1.12 (47.3)	1.69 (41.9)
11. Man-years urbanization (and percentage of 4)	.08 (5.7)	.11 (4.7)	.08 (3.4)	.19 (4.7)
12. Construction	.05	.07	.05	.10
13. Indirect	.03	.04	.03	.09

14. Man-years, dwelling and urbanization	1.49	2.47	2.45	4.22
15. Man-years promotion and sales	.04	.13	.16	.45
16. Total man-years	1.53	2.60	2.61	4.67
17. Labor earnings, construction, and indirect, dwelling only, 1970 U.S. dollars	$1,298	$2,110	$2,499	$3,222
18. Share in structural cost, percentage	45.1	41.5	39.2	35.2
19. Construction labor earnings	32.3	26.6	23.9	18.2
20. Indirect labor earnings	12.8	14.9	15.3	17.0
21. Materials costs, 1970 U.S. dollars	$1,642	$3,146	$4,197	$6,840
22. Share in dwelling cost, percentage	57.1	62.7	65.9	74.7
23. Share: Onsite labor costs to sum of onsite labor and materials, percentage	36.9	30.3	26.7	22.6

SOURCE: Data collected by Christian Araud and Santiago Rincón Gallardo, some of which is given in Christian Araud, Gerard Boon, Victor Urquidi, and Paul Strassmann, *Studies on Employment in the Mexican Housing Industry*, Development Center Studies, Employment Series No. 10 (Paris: OECD, 1973), especially pp. 80, 163. It was assumed that offsite construction labor is paid at double the rate of onsite labor. Other figures are empirical.

As may be seen in Tables A1 and A2, a minimal dwelling is included for single family housing, but not for multifamily units. Instead, a distinction is made between good housing in four- to five-story buildings and higher ones. Both have an identical floor space of 89.7 square meters. Luxury apartments are assumed to exist only in high-rises of about eight stories. A luxury apartment is less than one-third in size and value of a luxury house. Nevertheless, per square meter the luxury apartment costs more. A higher per square meter cost is true of all multifamily housing except the four- to five-story "good" category (see Tables A1 and A2, line 3).

The number of man-years per dwelling varies with its value, but less than in proportion. For minimal and low cost housing, construction labor is about 70 percent of all labor, but its share falls below 60 percent for luxury housing (line 5). For single family housing the offsite share of this total is always between 9 and 10 percent, but for high-rise multifamily housing, offsite labor is around 12 percent (line 9). A surprising finding was that skilled labor is used more than unskilled labor for all types except good and luxury single family housing (lines 7 and 8). An unskilled worker earned $888 and a skilled one $1,407 in 1970.

Where onsite labor has a smaller share, indirect labor in the materials necessarily has a larger share of man-hours. That is, the indirect labor share of employment rises with value from below 30 to above 40 percent (line 10). In terms of earnings, the indirect labor share rises from 12 to 17 percent of structural value, and it is always slightly higher for multifamily housing (line 20). The labor intensity of the materials themselves was in all cases around 22 percent. Construction labor falls with dwelling value from 32 to 18 percent and generally has a higher share for single family housing (line 19).

What matters is the combined effect. Here we find that minimal and low cost housing have an expenditure on labor of 43–45 percent; good housing, 39–42 percent; and luxury housing only 35–38 percent (line 18).

To these expenditures must be added cost and man-years for urbanization and promotion or sales. Urbanization adds about 5 percent more man-years for all housing except the cheapest single family types. There it will add 8 and even 16 percent (line 11). As a compensating factor, low cost housing is so uniform and in such short supply that it needs very little promotional expenditure, about one-twentieth of a man-year or some two weeks per dwelling. By contrast, one man-year is required to promote and to sell a luxury house (line 15). Its diversity has to be explained and the expense justified.

None of these employment and wage effects are sufficient to determine what kind of housing ought to be promoted by government to maximize employment. Government support will either replace or expand private spending on housing. To varying degrees for each income group, housing expenditures will leak into land purchases that create only a negligible amount of employment. When these factors were taken into account in Mexico, it was found that luxury single family housing creates only one-half as much employment as good housing, which, in turn, creates only one-fourth as much as low cost housing. The range was from two man-years per annual US$10,000 government subsidy to sixteen man-years.[2] This factor of eight is of far greater significance than the mere 22 percent higher labor intensity of luxury compared with low cost housing.

Appendix B

Substitution Elasticities in the Construction Sector of Nineteen Countries

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Substitution Elasticities in the Construction Sector of Nineteen Countries

Science is not only measurement of given data, but also its collection beforehand, preferably with some hypothesis in mind.[1] The computer has made measurement cheaper than collection. The temptation is to measure whatever flotsam and jetsam of numbers come one's way, like a whale blindly ingesting marine life. Whatever definitions, sampling techniques, and editing methods a statistical agency once used, if it produced a number, it was to be grabbed and fed in. High standards for data often compel one to gather one's own, as the group of the Colegio de Mexico did, reported in Appendix A. But being pernickety about data forces one to be content with case studies, while running the risk that the case may be atypical. A balanced diet might have the case study as the main course and the multicountry comparison as the salad. For better or worse, we have such comparisons.

The Sample

National construction statistics are available for very few poor or middle income countries in a continuous series extending from the 1950s into the 1970s. Hence, for all countries our study is limited to the eleven years 1960–1970. Only 19 countries had enough data to be deemed worthy of inclusion; of these, only seven had a complete set of

Table B1. ***Gross Domestic Product per Capita and Selected Construction Statistics for Nineteen Countries, 1960–1970***

Country	*1* Gross domestic product per capita[a]	*2* Average construction gross output per worker (1970 dollars)	*3* Construction value added per worker (1970 dollars)	*4* Hourly earnings (1970 dollars)	*5* Ratio of construction output to GDP, in percentage	*6* Ratio of value added to GDP, in percentage	*7* Ratio of materials to gross output, in percentage	*8* Construction materials consumed per worker (1970 dollars)
Kenya, 1964–1970	140	122.0	106.6	.31	7.0	4.0	48.0	89.8
Egypt, 1961–1968	217	—	—	.14	7.5	4.0	46.4	—
Korea, 1962–1970	256	2,266.7	754.8	—	13.0	4.3	66.7	1,511.9
Syria, 1963–1969	273	1,896.7	742.0	.28	7.4	3.0	61.0	1,154.4
El Salvador, 1961–1968	311	3,417.7	1,842.3	.32	5.5	3.0	46.1	1,575.3
Philippines, 1960–1968	344	1,846.6	723.9	—	7.6	3.0	60.8	1,122.7
Turkey, 1961–1970	363	6,022.8	3,137.7	.30	12.0	6.3	48.0	2,892.8
Peru, 1960–1969	374	—	—	.26	—	2.2	—	—
Cyprus, 1965–1970	824	1,717.4	1,488.2	.43	11.0	5.0	54.0	1,481.1
Spain, 1963–1970	964	3,558.8	1,531.0	.34	12.0	5.1	57.0	2,029.6
Argentina, 1960–1968	968	3,489.5	1,328.4	.51	7.7	2.9	57.3	2,000.4
Puerto Rico, 1960–1966	1,411	1,446.6	4,187.1	1.42	15.5	6.9	55.6	5,259.5
Israel, 1961–1970	1,836	10,860.8	4,673.8	.80	14.6	7.6	57.0	6,187.0
Austria, 1960–1970	1,946	7,405.6	4,701.0	.52	15.4	9.8	26.8	2,726.1
United Kingdom, 1960–1970	2,128	6,671.7	4,254.8	1.26	9.0	5.7	36.2	2,416.7
Belgium, 1960–1970	2,633	8,212.0	3,827.1	1.0	12.0	5.7	52.1	4,383.0
France, 1960–1970	2,901	8,536.5	5,733.4	.88	14.0	9.4	32.7	2,790.8
Sweden, 1962–1970	4,055	11,111.8	6,430.0	2.8	14.4	8.3	42.1	4,081.8
United States, 1960–1970	4,734	27,300.9	11,123.4	4.4	10.2	4.2	59.1	16,077.5

SOURCES: United Nations and OECD *Yearbooks of National Accounts, 1960–1970,* and ILO yearbook of Labor Statistics, supplemented by national sources.

[a] Last year in series in 1970 dollars.

eleven years available in the statistical library of the International Labour Office (ILO), where these calculations were made. No doubt the ILO failed to collect some statistical reports on construction wages, employment, and output that existed for additional non-European countries. (The number of European countries was held down in rough proportion to those from other continents.)

As a glance at Table B1 shows, the 19 countries include eight that may be classified as less developed or poor since their per capita domestic product was less than US$400 in the last year of the series. Included are three in the Middle East, two in the rest of Asia, one in sub-Saharan Africa, and two in Latin America. These countries are Egypt, Syria, Turkey, the Philippines, the Republic of Korea, El Salvador, Peru, and Kenya. Five countries are at intermediate income and development levels, that is, with per capita products between US$800 and $1,900: Cyprus, Israel, Spain, Argentina, and Puerto Rico. Six advanced countries were selected: Great Britain, Belgium, France, Austria, Sweden, and the United States.

Listed below are the data gathered for the entire construction sector, including nonresidential building and civil engineering. Separate labor and materials data for housing are rarely available.

O = gross output;
V = value added;
M = materials consumed, defined as $(O - V)$;
L = employment (sometimes an index);
w = labor earnings; and
m = the materials price index.

Results

Something disturbing appeared almost at once. As shown in Table B2, for a number of countries various elements had negative growth rates. The declines were not due to the accident of a high first and low final year, since the growth rate used was the least-squares slope coefficient for the logarithms of all observations. Apparently, a decade is not enough time to overcome the effect of the marked fluctuations that affect construction everywhere.

The worst case was Egypt, which had declines in output, value added, and in the ratio of these two to employment, or "productivity," O/L and V/L. In Syria, wages seemed to have a negative trend. Great Britain and Israel had negative employment trends. El Salvador had a

Table B2. ***Growth Rates and Ratios in Construction in Nineteen Countries***

Country	*Growth rates, logarithmic fits, in percentage*						*Growth rate of ratios*		*Ratio of growth rates*
	1 *O*	2 *V*	3 *L*	4 *w*	5 *m*	6 *GDP*	7 *O/L*	8 *V/L*	9 $\frac{w}{m}$
Kenya	14.4	11.7	6.0	14.2	—	7.0	7.9	5.3	—
Egypt	−2.6	−1.2	4.9	1.1	2.8	4.5	−7.2	−6	.39
Korea	22.9	21.8	8.7	—	12.0	10.7	13.0	12.0	—
Syria	7.1	5.7	1.0	−1.9	3.3	4.2	6.1	4.7	−.58
El Salvador	6.3	7.4	10.9	1.6	−1.7	6.6	−4.2	−3.2	−.94
Philippines	4.8	4.3	5.5	—	3.4	4.7	−.6	−1.05	—
Turkey	11.2	7.7	9.6	4.5	4.8	6.3	1.5	−1.7	.94
Peru	—	4.8	5.7	3.2	7.9	5.4	—	−0.9	.40
Cyprus	12.5	11.5	5.0	8.7	—	7.4	7.1	6.2	—
Spain	6.3	7.5	5.1	7.1	1.7	6.1	1.1	2.3	.32
Argentina	2.6	2.9	3.16	4.7	24.2	3.8	−0.5	−0.2	.19
Puerto Rico	12.5	10.4	5.5	2.8	1.8	7.4	6.6	4.6	1.55
Israel	2.4	4.8	−0.2	3.9	3.7	7.9	2.6	5.1	1.05
Austria	6.0	5.9	.27	2.6	2.9	3.6	5.8	5.6	.90
United Kingdon	4.9	2.6	−0.4	4.1	3.0	3.9	5.2	3.0	1.37
Belgium	4.0	3.5	2.0	3.4	3.6	3.7	1.9	1.4	.94
France	9.5	7.7	3.5	2.2	3.3	4.2	5.8	4.1	.67
Sweden	4.3	3.7	2.3	3.1	3.2	4.5	1.9	1.3	.97
United States	2.6	1.1	2.1	2.7	1.9	4.4	.5	−1.0	1.42

SOURCES: United Nations and OECD *Yearbooks of National Accounts*, and ILO yearbook of Labor Statistics, supplemented by national sources.
NOTE: *O* = gross output; *V* = value added; *L* = employment; *w* = labor earnings; *m* = materials price index.

negative trend in materials prices, as well as in value added and output per worker.

Both *O/L* and *V/L* declined for the Philippines and Argentina. Only *V/L* declined for Peru, Turkey, and the United States. Among poor and middle income countries, only five (Kenya, Korea, Cyprus, Spain, and Puerto Rico) had no negative growth rates in any element. Among advanced countries, only the two slowest performers, Great Britain and the United States, had negative elements, one each.

Negative growth rates in *O/L* and *V/L* may not be a calamity from the point of view of the country in which they occur, nor from that of economic analysis. Where unemployment exists, a fall in wages compared with other prices might mean more jobs, even though some of these might have less productivity than the average, being marginal. These additional jobs would thus cause negative growth in *V/L* and *O/L*. What would be disturbing would be a decline in average productivity that is associated with a rise in wages compared with other prices, specifically those of materials.

In our sample, that disturbance did not arise. For the Philippines no wage trend is available. Five poor or middle income countries (Egypt, El Salvador, Peru, Turkey, and Argentina) had declines in average productivity. In four of these (not El Salvador) the growth rate of wages was less than that of materials ($\dot{w}/\dot{m} < 1$), and these are the only such countries for which this was the case. More workers were employed at lower productivity, relatively low wage rises keeping such increased employment viable. Among advanced countries, however, two countries seriously contradicted this pattern, France and the United States.

Only one other observation about the table of growth rates will be made here. The six advanced countries show no pattern in the relative rates of construction and GDP growth. In some, such as the United States and Sweden, GDP grew faster; in others, such as France and Austria, construction grew faster. But among the poor and middle level countries, the association of a faster construction growth rate with a high GDP growth rate and vice versa was very strong. (Yule's Q = .846.)

	GDP growth rate above 6 percent	*GDP growth rate below 6 percent*	
Construction output and value added grew: Faster than GDP	6 countries	1 country	7
Slower than GDP	2 countries	4 countries	6
Total	8 countries	5 countries	13

To measure the substitution elasticities, a number of standard and bizarre regressions were run, leading to mixed results. Space precludes giving all results here, especially when they were very poor, as with variable elasticity of substitution specification. Only the results of four equations with and without a time trend will be given in Tables B3, B4, B5, B6, and B7. First is the standard approach with value added per worker (*V/L*) as the dependent variable and the wage rate (*w*) as the independent one, both in logarithms. The slope coefficient of the independent variable is the constant elasticity of substitution (CES), as has been learned from Arrow-Chenery-Minhas-Solow.

For a cross-country set of 15 averages, this elasticity, given in chapter 1, was 0.79. In detail, for this specification, as seen in Table B3, column 1, the elasticities range from an irascible −2.13 to a heartening +1.76 for Austria. As a warning there is a −.38 for the United States, which contradicts the +1.12 that Cassimatis found for 1948–1964. Cassimatis, however, insisted that time series data for production functions are acceptable only if "restricted to those years in which the industry performed at or near capacity."[2] During the late 1960s financial contractions associated with the Vietnam War and balance-of-payments crises brought U.S. construction far below capacity. Value added in construction rose at one-fourth the growth rate of GDP during the decade, and gross construction at a 60 percent rate. With this experience in mind, perhaps one should take most seriously those countries in the sample in which construction expanded fast enough to keep the industry near capacity. Anything faster than 6 percent would seem to meet that condition. For good measure, only countries without negative trends elsewhere should be considered. The resulting set of countries is Kenya, Korea, Cyprus, Spain, Puerto Rico, France, and Austria. To this group one might add Israel, where GDP grew at a fast enough rate, 7.9 percent, and the construction labor force was stable, declining at a negligible 0.2 percent per year.

For these high growth countries, the elasticity still ranges widely (from the Spanish .30 to the Austrian 1.76), but the average is a nice 0.96, almost unity. For the five advanced European countries, regardless of growth (Great Britain, Belgium, France, Austria, and Sweden), the average elasticity is a bullseye 1.01.

A substitution elasticity that relates the average productivity of labor to gross output instead of value added gives more scope for registering materials-labor substitution, as this study reiterates. The cross-country set of 15 averages gave a level of .86 for *O/L* and only .79 for *V/L*. Indeed, all the elasticities should be higher, and so they are.

Table B3. *Elasticities of Substitution and R^2 in Construction for Selected Countries during the 1960s with Alternative Estimating Equations*

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Dependent variable	*V/L*	*O/L*	*w/m*	*O*	*V/L*	*O/L*	*w/m*	*O*
Independent variables	*w*	*w*	*M/L*	*L, M* $[L-M]^2$	*w, t*	*w, t*	*M/L, t*	*L, M* $[L-M]^2$ *t*
Country								
Kenya	.35 (.356)	.53 (.632)	—	.38 (.973)	−1.2 (.556)	−1.0 (.785)	—	.28 (.996)
Egypt	−.98 (.094)	−.12 (.003)	4.8 (.304)	.02 (.989)	−.14 (.781)	.33 (.689)	4.15 (.311)	−3.3 (.996)
Korea	—	—	—	.25 (.999)	—	—	—	.28 (.999)
Syria	−.96 (.146)	−.71 (.051)	4.23 (.175)	−.79 (.898)	.46 (.468)	1.6 (.601)	5.31 (.990)	1.36 (.998)
El Salvador	−2.13 (.692)	−2.11 (.585)	−3.30 (.467)	1.22 (.967)	−2.24 (.694)	−1.76 (.608)	−12.97 (.855)	1.78 (.971)
Philippines	—	—	—	−.10 (.996)	—	—	—	.09 (.996)
Peru	−.42 (.212)	—	—	—	−.93 (.299)	—	—	—
Turkey	−.40 (.684)	.29 (.463)	−15.5 (.046)	.98 (.998)	−.42 (.684)	−.25 (.604)	−5.8 (.059)	.98 (.998)
Cyprus	.69 (.965)	.73 (.832)	—	.17 (.998)	.28 (.992)	−.40 (.986)	—	.30 (.999)
Argentina	−.05 (.189)	−.10 (.198)	.22 (.198)	.58 (.998)	−.17 (.248)	−.12 (.198)	1.9 (.989)	.72 (.999)
Spain	.30 (.436)	.13 (.135)	−144.9 (.00001)	1.02 (.991)	−1.6 (.715)	−1.6 (.522)	−4.3 (.977)	1.01 (.999)
Israel	.77 (.313)	.49 (.391)	2.58 (.278)	.86 (.895)	−.96 (.767)	−.18 (.600)	2.54 (.279)	.92 (.923)
Puerto Rico	1.15 (.890)	1.32 (.896)	1.9 (.843)	−.03 (.996)	−.33 (.993)	.35 (.930)	7.5 (.944)	.09 (.999)
United Kingdom	.74 (.898)	1.25 (.947)	8.5 (.796)	−.06 (.998)	.74 (.898)	.60 (.954)	8.6 (.796)	−.06 (.998)
Belgium	.43 (.596)	.56 (.660)	−17.12 (.069)	.61 (.989)	.63 (.600)	.63 (.660)	−28.98 (.0767)	.74 (.989)
France	1.68 (.905)	2.38 (.895)	−.10 (.632)	.81 (.998)	−.41 (.990)	−.17 (.958)	−.055 (.661)	.51 (.999)
Austria	1.76 (.807)	1.80 (.812)	−16.4 (.093)	.12 (.999)	−.14 (.996)	−.11 (.996)	−4.03 (.102)	.03 (.999)
Sweden	.46 (.539)	.61 (.723)	549.4 (.0003)	2.81 (.967)	1.42 (.582)	.30 (.727)	10.48 (.030)	1.12 (.974)
United States	−.38 (.703)	.18 (.210)	2.53 (.519)	.32 (.987)	−2.39 (.798)	−2.74 (.464)	4.24 (.586)	.46 (.992)

NOTE: *O* = gross output; *V* = value added; *M* = materials consumed, defined as (*O* − *V*); *L* = employment; *w* = labor earnings; *m* = materials price index; and *t* = time.

Table B4. ***Intercept (a) and Standard Errors (Sa) of Slope Coefficient of Countries with Alternative Estimating Equations,*** **Not** ***Including a Time Variable***

Dependent variable	*V/L*		*O/L*		*w/m*		*O*	
Independent variable	*w*		*w*		*M/L*		*L, M,* $[L-M]^2$	
Country	*a*	*Sa*	*a*	*Sa*	*a*	*Sa*	*a*	*Sa*
Kenya	−1.10	.529	−1.30	.459	—	—	1.09	.566
Egypt	1.09	1.464	−.49	2.031	.40	.025	−.12	.177
Korea	—	—	—	—	—	—	.27	.078
Syria	2.48	2.307	2.33	3.032	.17	.053	.02	.335
El Salvador	−2.86	.118	−2.59	.147	−2.95	.330	−5.50	5.811
Philippines	—	—	—	—	—	—	.50	.405
Peru	2.27	.581	—	—	—	—	—	—
Turkey	−4.15	−.115	−4.75	.131	−1.11	.461	40.75	21.051
Cyprus	−1.08	.057	−.78	.145	—	—	−.02	.429
Argentina	−.77	.202	−.15	.386	6.55	3.076	1.39	1.882
Spain	−4.51	.170	−3.93	.162	−.85	3.727	−85.18	120.808
Israel	−.99	1.061	.14	.563	.14	.259	30.71	10.485
Puerto Rico	−1.41	.282	−1.32	.313	−.69	.048	−.51	.363
United Kingdom	−1.07	.130	−1.69	.155	−.44	.004	1.02	.278
Belgium	−1.91	.297	−1.89	.334	.41	.055	1.68	1.349
France	−2.55	.097	−2.76	.144	1.68	.050	4.02	1.478
Austria	−2.83	.295	−2.68	.299	−1.08	.080	.66	.217
Sweden	.93	.170	1.003	.154	−.99	.158	−1.01	7.159
United States	−1.85	.044	−1.76	.064	−.74	.240	.46	4.737

NOTE: *a* = intercept; *Sa* = standard error; *O* = gross output; *V* = value added; *M* = materials consumed, defined as $(O-V)$; *L* – employment; *w* = labor earnings; and *m* = materials price index.

Table B5. *Intercept (a) and Standard Errors (Sa) of Slope Coefficient of Countries with Alternative Estimating Equations,* Including *a Time Variable*

Dependent variable	V/L		O/L		w/m		O	
Independent variable	w		w		M/L		$L, M, [L-M]^2$	
Country	*a*	*Sa*	*a*	*Sa*	*a*	*Sa*	*a*	*Sa*
Kenya	2.46	2.696	2.28	2.153	—	—	1.03	.251
Egypt	.38	.808	−.45	1.274	.39	.042	.05	.153
Korea	—	—	—	—	—	—	.34	.119
Syria	−.76	2.916	−2.96	3.148	.17	.590	1.14	.410
El Salvador	−2.81	.197	−2.49	.241	−2.45	.234	−2.55	7.634
Philippines	—	—	—	—	—	—	.54	.472
Peru	3.13	−1.256	—	—	—	—	—	—
Turkey	−4.12	.394	−4.13	.386	−1.64	1.661	41.71	21.928
Cyprus	−.78	.097	.051	.15	—	—	.40	.129
Argentina	−.22	.821	.06	1.626	3.34	.920	2.73	1.439
Spain	−2.50	.915	−2.11	.915	−1.87	.622	−85.94	27.761
Israel	3.36	1.348	1.80	.996	.14	.281	13.41	16.210
Puerto Rico	.74	.294	.085	1.052	−.58	.054	.57	.136
United Kingdom	−1.08	.823	−.73	.918	−.44	.048	1.02	.302
Belgium	−2.38	1.683	−2.06	1.900	.43	.099	2.63	1.222
France	−1.57	.122	−1.56	.359	−1.58	.130	.913	1.997
Austria	−1.03	.096	−.86	.109	−1.34	.941	.16	.285
Sweden	−.03	1.244	1.32	1.170	−1.10	.310	−4.13	7.817
United States	−.91	.481	−.40	.704	−1.05	.363	−2.76	4.239

NOTE: a = intercept; Sa = standard error, O = gross output; V = value added; M = materials consumed, defined as $(O - V)$; L = employment; w = labor earnings; and m = materials price index.

Table B6. *Array of Countries within Ranges of Substitution Elasticities Determined by Alternative Estimating Equations,* Not *Including a Time Variable*

Dependent variable	*Independent variable*			*Elasticity ranges*		
		2 +	*1.0–1.99*	*.3–.999*	*0–.299*	*Below 0*
$\frac{V}{L}$	w		*Austria* *France* *Puerto Rico*	*Belgium* *United Kingdom* *Israel* *Sweden* *Spain* *Kenya* *Cyprus*		*United States* *Turkey* Peru Argentina *Egypt* *El Salvador* Syria
$\frac{O}{L}$	w	*France*	*Austria* *United Kingdom* *Puerto Rico*	*Belgium* Israel *Sweden* *Kenya* *Cyprus*	Turkey United States Spain	Argentina Egypt *El Salvador* Syria
$\frac{w}{m}$	$\frac{M}{L}$	*United Kingdom* *United States* Israel Sweden Egypt	*Puerto Rico*		Argentina	Austria Belgium *France* Turkey El Salvador Spain Syria
O	L M $[L-M]^2$	*Sweden*	*El Salvador* *Spain*	*Belgium* *Israel* *France* *United States* *Korea* *Turkey* *Argentina* *Kenya*	*Austria* *Egypt* *Cyprus*	*United Kingdom* *Puerto Rico* *Philippines* *Syria*

NOTE: Countries shown in italics had regressions with R^2 of .500 or higher. O = gross output; V = value added; M = materials consumed, defined as $(O - V)$; L = employment; w = labor earnings; and m = materials price index.

Table B7. *Array of Countries within Ranges of Substitution Elasticities Determined by Alternative Estimating Equations*, **Including a Time Variable**

Dependent variable	*Independent variable*	*Elasticity ranges* 2 +	1.0–1.99	.3–.999	0–.299	Below 0	
$\frac{V}{L}$	w, t		*Sweden*	*Belgium* *United Kingdom* Syria	*Cyprus*	*Austria* *France* *United States* *Puerto Rico* *Israel* Peru *Turkey*	Argentina *Egypt* *El Salvador* *Spain* *Kenya*
$\frac{O}{L}$	w, t		*Syria*	*Belgium* *United Kingdom* *Puerto Rico* *Egypt*	*Sweden*	*Austria* *France* United States *Israel* *Turkey* Argentina	*El Salvador* *Spain* *Kenya* *Cyprus*
$\frac{w}{m}$	$\frac{M}{L}$, t	*United Kingdom* Israel *United States* *Puerto Rico* Sweden Egypt *Syria*	*Argentina*			*Austria* Belgium *France* Turkey *El Salvador* *Spain*	
O	L M $[L-M]^2$ t		*Sweden* *El Salvador* *Spain*	*Belgium* *France* *United States* *Israel* *Korea* *Turkey* *Argentina* *Kenya* *Cyprus*	*Austria* *Puerto Rico* *Philippines*	*United Kingdom* *Egypt* *Syria*	

NOTE: Countries shown in italics have regressions with R^2 of .500 or higher. O = gross output; V = value added; M = materials consumed, defined as $(O - V)$; L = employment; w = labor earnings; m = materials price index; and t = time.

The range in column 2, Table B3, is from −.71 to 2.38. For the high growth countries, the average elasticity now exceeds unity with 1.05. In the five advanced European countries, the elasticity rises to 1.32.

Obviously, with such figures there is multicollinearity in the basic data that is stronger the higher the rate of growth. Hence, the introduction of the time variable makes the elasticity negative for the subset of high growth countries, while only reducing it to .45 for *V/L* and .25 for *O/L* in the subset of advanced European countries. (See Table B3, columns 5 and 6.)

To regress the logarithms of *w/m* against those of *M/L* seemed the most direct way to arrive at materials-labor substitution, but the results were not very good. Table B3, columns 3 and 7, shows a bizarre range of elasticities and very low coefficients of determination. Only for Puerto Rico is the R^2 above .800, and here the elasticity is 1.90 (without a time variable).

The poor results may well be due to the unreliability of *m*, the materials price index. When materials are substituted for labor, it is not materials in general, those that cost the average price, but more of some specific material that is more easily handled. Only the relative price of this material, compared with those previously used, matters, not the general trend. Indeed, the specific prices of individual materials often move at quite different rates. Other regressions using *m*, not shown in the tables, led to similarly poor results with low R^2.

Another way of arriving at materials-labor substitution that is clearly distinct from capital-labor substitution is to use the estimating equation proposed by Jan Kmenta:[3]

$$\log O_t = \beta_1 + \beta_2 \log M_t + \beta_3 \log L_t + \beta_4 (\log M_t - L_t)^2 + e_t.$$

In this case the substitution parameter is[4]

$$\rho = \frac{-2\beta_4\beta_2 + \beta_3)}{\beta_2\beta_3},$$

and the elasticity of substitution becomes

$$\sigma = \frac{1}{1+\rho}.$$

As may be seen in columns 4 and 8 of Table B3, the results are not an econometrician's dream, but they look somewhat better than what we have had so far. Whether or not a time variable is included, only two elasticities are definitely negative. None are absurdly high. Five countries have elasticities in the .8 to 1.2 range that fit the pattern of a stable share of wages. For the five advanced European countries, the average elasticity without a time variable is .88 (mainly due to a high value for Sweden), but this falls to .47 with a time variable (as Sweden falls to 1.12). For the high growth countries, the average elasticity is only .46, but this rises with a time variable to .74. These regressions had the highest coefficients of determination.

Tables B6 and B7 show which countries fit into what elasticity range in accordance with different estimating equations. Underlined countries had an unadjusted R^2 of .500 or higher, which in these samples meant significance at the .05 level or better.

Note on Data Sources and Adjustments

Initially, the hope was to use a sample of countries much larger than 19. Unfortunately, in Geneva a minimum of information was available for six years or more for only 13 developing and intermediate countries. With personal visits to government statistical offices throughout the world, it might have been possible to double or triple this sample. In time, Geneva, possibly the ILO, should become a first-class repository for statistical reports of this type. In addition to the few available and adequate national reports, the following international compendia of statistics were used:

National Accounts of O.E.C.D. Countries 1960–1971 (Paris: Department of Economics and Statistics, OECD, 1973);

Labour Force Statistics (Basic Statistics O.E.C.D.) 1959-1970 (Paris: Department of Economics and Statistics, OECD, 1972);

Statistics of the Occupational and Educational Structure of the Labour Force in 53 Countries (Paris: OECD, 1969);

Year Book of National Accounts Statistics United Nations (New York: Statistical Office of the United Nations, Department of Economic and Social Affairs, 1968 through 1973);

United Nations, *Statistical Year Book* (New York: Statistical Office of the United Nations, 1960–1964, 1968–1969, 1970–1971).

Year Book of Labour Statistics (Geneva: ILO, 1960, 1963, 1964, and 1968–1973);

Boletín Estadístico de América Latina (New York: United Nations Comisión Económica para América Latina, 1970 through 1972);

Boletín Económico de América Latina (New York: United Nations, 1971 through 1973);

América en Cifras (Washington, D.C.: Inter-American Statistical Institute, 1970); and

Statistical Year Book (Addis Ababa: United Nations Economic Commission for Africa, 1974).

The variables used had to be converted to constant prices or indices. For eleven countries the most convenient base year was 1963. In addition, we had the following: Puerto Rico 1954, Cyprus 1958, Argentina 1960, Turkey 1961, El Salvador 1962, Kenya and Israel 1964, and Korea 1965. For multicountry estimates, the base year chosen was 1965.

Construction output data were available at market prices for all countries except Turkey, for which factor prices were used. For value added, market prices were used for Peru, Sweden, Great Britain, and the United States; factor prices were used for the rest. In the case of Israel three somewhat divergent statistical series for the years 1961–1964 were averaged. For the same period Egyptian data were adjusted on the assumption that the share of value added in gross construction rose from 49.3 percent in 1960 to 57.3 percent during 1965–1969 at a uniform compound rate. Since materials use was defined as the difference between output and value added, the use of market and factor prices in estimating the difference may have led to some distortion of results. For GDP, market prices were used except for Belgium, Korea, Turkey, and El Salvador, which had factor prices. For conversion to constant prices, the GDP deflator was used.

Employment consists of civilian labor force employed, as defined in the ILO *Year Book of Labour Statistics*. Indices were used for Egypt and Peru.

For wages, the concept actually used was "hourly earnings" whenever possible. When earnings were reported on a daily, weekly, monthly, or annual basis, an estimate had to be found or made for the number of hours in these aggregates. For Belgium, the number of weekly hours used was 40; for developing countries, it was 44. Building materials price indices involved the same problems of converting bases and splicing different series. As in the case of Austria, often the index was only for residential building materials and applied only to the capital city.

Appendix C

Mass Production of Dwellings in Colombia: A Case Study

Mass Production of Dwellings in Colombia: A Case Study

Choice of technology is particularly interesting in those countries that have given dwelling construction high priority. Outstanding among these is Colombia, which gave it highest priority during the economic plan of 1971–1974. This emphasis was a shift from the 1960s, when Colombia spent less on dwelling construction than the average developing country. A 2.5 percent share of GDP was typical, but Colombia spent only 0.9 percent in 1967.[1] In terms of area, the volume fluctuated around 3.8 million square meters during the 1960s. By 1971, volume had risen to 4.2 million square meters, worth seven billion pesos (US$333 million), and a further expansion of about 30 percent was planned.[2]

Housing and Employment Statistics

This expansion partly reflected the growing need for shelter. Towns with populations of over 30,000 were growing collectively by 100,000 households a year around 1970, implying a minimum need for that many additional urban dwellings annually. In 1967, however, only 40,000 were built or rehabilitated, thus raising the deficit by 60,000 dwellings. According to the Instituto de Crédito Territorial, the government low cost housing bank and builder, the deficit had reached

300,000 dwellings by 1969. An equal number of dwellings lacked water, sewerage connections, or electricity. Given the trend, an intolerable deficit of eight million would exist by the year 2000.

But expansion of dwelling construction aimed not only at the growing deficit of shelter but also at reducing unemployment. In 1970 an international mission to Colombia concluded that "a rise by one-third in the construction industry's share of total employment in Colombia therefore seems reasonable, even conservative."[3] Perhaps, construction employment (including public works and all building) could move toward 15 percent of nonagricultural employment.

In Colombia, all construction as a share of GDP wavered between 2.5 and 3.7 percent during 1950–1970. The lower percentage applies to 1951–1952, with a second trough of 2.7 percent in 1964–1965. The peaks occurred in 1955–1956 and 1969–1970.

The share of the labor force in construction meanwhile rose steadily from 3.5 percent (1951) to 5.8 percent (1970). Some of this rise undoubtedly reflects an increase in sectoral unemployment, which in turn reflects population growth and migration from the countryside. Construction is the first sector that migrants enter, often raising unemployment disproportionately in this industry. In the city of Cali, for example, 80 percent of construction workers had migrated from elsewhere. Nevertheless, the higher growth of construction labor compared with construction output also was accompanied by a higher share of labor earnings in construction value added.

Year	*Construction workers as a percentage of the economically active population*	*Earnings of labor as a percentage of construction value added*
1951	3.5	75.4
1964	4.3	73.8
1967	5.4	77.4
1970	5.8	81.0

Unemployment, it appears, did not grow sufficiently to keep *both* the number working and the share of labor from moving up together. In fact, since construction earnings lagged, employment had to rise *faster* than output to account for a rising share of labor. In Bogota the real wages of unskilled construction workers even fell by almost 20 percent from 1965 to 1972. Labor was substituted for other factors of production with an elasticity greater than unity.[4]

The National Statistical Department (DANE) has begun estimating the relative rise of materials prices and labor costs for three housing prototypes in ten Colombian cities. Preliminary indications for the early 1970s are that materials rise faster than labor in the largest four cities (Bogota, Medellín, Cali, and Barranquilla); about equally in the next two (Bucaramanga and Cúcuta); and less than labor in the last four (Manizales, Cartagena, Neiva, and Pasto). Variations in the supply conditions of both labor and materials appear to be involved in this curious pattern.[5]

General statistics on urban housing can be found in Table C1. While the number of urban families increased at a 6.1 percent rate, the number of dwellings rose only at a 5.6 percent rate. Dwelling construction, either in terms of value or square meters, rose only at the 4 percent growth rate of national product. Apparently, new dwellings not only were built smaller, but also were created by subdividing older dwellings. This deterioration and the growing deficit raised the temptation to experiment with novel mass production technology, although the cost per square meter had hardly risen in real terms during these decades. Variations in cost were probably due to the average quality of what was built, rather than to changes in efficiency.

One cannot, of course, build more houses than people can afford or than the government can afford to subsidize. Colombian policy in the early 1970s aimed at expanding the housing market by linking mortgage payments and investments to a rising index. A rising payment financing system had also been recommended by the 1970 mission.[6] In addition, reductions in the cost and price of dwellings would be desirable, especially if followed by a positive effect on employment via the elasticity of demand. This hope for lower costs spurred experiments with mass production.

Colombian Experience with Rationalization and Prefabrication

As did the other Latin American countries, Colombia gained experience with rationalization and prefabrication during the 1960s. By 1965, for example, the Instituto de Crédito Territorial (ICT) had designed a house for self-help construction that consisted of only 50 components. All of these could be handled by two men so that heavy equipment was not needed for construction. Precase stairs, beams, window frames, and the like were made at the institute's own three plants, but the concrete blocks came from commercial suppliers. Except for their modular size, there was nothing special about the blocks.

Table C1. ***Colombia: Urban Families, Housing, and Dwelling Construction, 1951–1969***

Year	*Urban families (thousands)*	*Number of dwellings (thousands)*	*Value of dwelling construction, in thousands of 1963 U.S. dollars*	*Square meters of dwelling (thousands)*	*Value of construction per square meter, in 1963 U.S. dollars*
1951	772	660	40,500	1,885	21.50
1952	819	697	46,300	2,160	21.40
1953	868	736	50,000	2,334	21.40
1954	921	778	63,900	2,913	21.90
1955	976	821	56,000	2,586	21.70
1956	1,035	867	57,500	2,713	21.20
1957	1,098	915	64,400	2,877	22.40
1958	1,164	965	68,800	3,117	22.10
1959	1,234	1,019	79,600	3,490	22.80
1960	1,309	1,075	71,[illegible]0	3,198	22.40
1961	1,3[illegible]8	1,134	88,700	3,657	22.25
1962	1.472	1,196	83,500	3,943	21.20
1963	1,560	1.261	88,200	3,844	22.90
1964	1,674	1,344	89,400	3,912	22.55
1965	1,775	1,417	89,800	3,861	23.15
1966	1,882	1,494	88,000	3,848	23.30
1967	1,996	1,574	94,900	3,747	23.50
1968	2,117	1,658	82,100	3,985.5	23.80
1969	2,244	1,747	--	2,982.5	20.60

SOURCE: *Boletin Mensual de Estadistica,* DANE, nos. 262–63 (May–June 1973): 36, 90, and sources there cited.
NOTE: 9 pesos = US$1.00. One cannot assume that the difference between succeeding figures in column 3 corresponds to the construction in columns 4 and 5. The differences in effect refer to mid-year figures; include other changes in the housing stock, such as demolition, shack building, and subdivision; and in addition come from a different source.

The modular size of all components eliminated site fitting and was thought to reduce waste of materials from 5 to one percent. The asbestos cement *canaletas* for the roofs came from a monopolistic commercial supplier; under ICT pressure he reduced his initial price quotation by half. In 1968 materials for a two-story dwelling of 78 square meters cost US$882.

Using professional labor, the ICT house could be built with 507 man-hours, or 6.5 man-hours per square meter. This amount was about one-third the comparable figure for a standard two-story dwelling. At US$1 per day, the implied labor costs were thus US$507, or 36 percent of labor and materials combined. If about US$256 was added for ICT administrative costs per house, the total without land came to about US$1,754. Construction costs per square meter were US$22.50, not much below those of conventional houses.

Since the ICT houses were intended for self-help construction, the man-hours per square meter were naturally much higher than 6.5. Initially they were 25, but design improvements reduced them to 11.3. The most difficult work was masonry, and many potential self-help owners preferred to contract out this task. Walls accounted for about 30 percent of the man-hours and 23 percent of materials. No one was supposed to contract out land clearing, staking out the house, excavation, and laying foundations and the first-floor slab, but it was reported that in some cities this was done for 90 percent of the self-help work. Project managers did not object since it raised quality and speed. Nevertheless, it contradicted the mutual-aid cooperative ideology behind the system.

By 1970 the Medellín branch of the ICT was abandoning the self-help system altogether and was building more rudimentary structures for US$130 on utility-supplied sites of about equal value. Completion would depend on genuine self-help. The earlier design had not been within the means of the poorer half of the population, even with self-help.[7]

In Copenhagen in August 1967, the United Nations and the Danish government sponsored the Seminar on Prefabrication of Houses for Latin America. For Colombia the following building systems were reported as of particular interest: (1) prefabricated houses having concrete panels for walls and 7.5 centimeter shell roofs, produced and assembled by the vacuum-concrete process; (2) lightweight prefabricated concrete panels used within modular systems (extruded panels, partially finished framed panels, and so forth); (3) prestressed concrete prefabricated columns, beams, and slabs; (4) multistory apartment buildings that use a heavy prefabrication system. Maximum size of the panels is 11.44 × 2.60 meters, maximum weight is seven metric tons, and the bathroom block weighs six metric tons; (5) prefabricated houses transported and assembled as room units fully completed in factory. The units are connected together on-site as two-room, four-room, and six-room houses and are finished for occupation in a mean construction time of eight days; (6) prefabricated metal frame houses with concrete sandwich panels, filled with treated wood-chip insulation for partitions and facades, supplied with glazing and prefitted plumbing in walls; and (7) partial concrete prefabrication and modular coordination in housing construction by aided self-help. The main housing agency (ICT) had already obtained enough favorable results to set up three prefabrication plants in different cities of the country. Prefabricated elements included lintels, beams, door and window frames, staircases, and floor slabs.

The total capacity of all these systems was said to be 100,000 square meters of dwellings per year, or 2.5 percent of all housing construction. The hope was that the better quality of these systems, as well as their speed of erection, given a sufficient volume of support, would make them economically competitive with conventional building.[8] Few of these hopes were realized.

A Survey and a Seminar

Another survey of prefabricated component innovations in Colombia was made by Santiago Luque Torres in 1971. His findings are summarized in Table C2. Only reinforced concrete components, of no more than moderately ambitious character, had been successfully introduced in low cost housing. The ICT components alone could be produced on a scale that made volume an advantage, while in all other cases volume was at best not a handicap, according to Luque. At the same time, he had his doubts about the quality of the ICT products. Wherever quality was positively favorable in other systems, costs became too high except for certain lightweight cement and asbestos cement components. In the case of pressed concrete sheets and reinforced ceiling beams, costs were favorable and quality neutral.

Least successful were the six attempts to introduce heavy concrete load-bearing panels; quality, volume, and cost all proved unfavorable. Prefabricated metal and pressed wood houses were not too dependent on volume, but they lacked quality and cost advantages, hence applicability in low cost housing. In the production of most components, off-site quality control was a problem and was attained only at undue cost. Moving equipment to the site was a help for quality coordination but feasible only for some of the concrete products already mentioned. The Outinord system of prefabricated formwork was also excessively dependent on volume.[9]

At the First Latin American Seminar on Prefabrication for Low-Cost Housing, 19–24 April 1971, in Bogota, Luque discussed his findings. Success had been attained in only three general types of cases. Most notable were ceiling beams. Not being visible, their quality primarily had to be structural, not aesthetic. Further beam innovation had gone in the direction of lighter weight cements and pre- or post-tensioning. Production at the site was feasible for some systems.

Prefabrication of small components such as bricks, blocks, tiles, window frames, and basins was also widespread and important but hardly novel. The convenience of larger sizes for sitework was more than offset by inconvenience in fabrication and transport.

All other types of prefabrication, both larger and more visible, had gained success only under the auspices of large integrated enterprises for high quality construction. Only such enterprises could command the needed extra capital and managerial and technical skill. They would turn toward advanced prefabricated components, not to save resources, but to gain time in projects that were extravagant in other respects as well.[10]

An Argentine architect, member of the Argentine Institute for Materials Rationalization, spoke at the seminar and warned that building systems from industrialized countries might not be suitable for Latin America. Specifically, it would be an error to foster total prefabrication of dwellings with heavy components in closed systems: "Prefabrication, or better, the industrialization of construction, should rise in direct proportion to the degree of development, going from prefabrication of small components — which need only a small rise in equipment investment and therefore allow sensitive adjustments to market fluctuations — to total prefabrication, which takes great capital expenditures hence a reliable market for reaching an optimal yield."[11]

The 98 Colombian and 17 other Latin American architects, builders, and materials producers at the seminar nevertheless favored greater spread of prefabrication in the official resolutions that were adopted. They believed that both urbanization and the wages of skilled workers were rising too fast to do otherwise. At the same time, industrial skills had advanced sufficiently to allow better use of technology from abroad. Preference should, however, go to the lightweight, open,

Table C2. ***Some Characteristics of Prefabricated Building Innovations Attempted in Colombia in Recent Years***

Item, sponsor, place	*Plant mobile*	*Used successfully in low cost housing*	*Quality*	*Adequacy Volume*	*Cost*
1. Reinforced concrete prefabricated parts; ICT; Bogota, Bucaramanga, Medellín	No	Yes	–	+	+
2. Outinord prefabricated formwork; Llorente and Ponce, Florez Carrero; Bogota	Yes	No	+	–	–
3. Pressed concrete sheets; Velez Saenz; Manizales	Yes	Yes	0	0	+
4 Reinforced ceramic ceiling beams; three firms; Bogota	Yes	Yes	0	0	+
5. Reinforced concrete ceiling beams and panels; various firms in various cities	No	Yes	±	0	–
6. Wooden components; various firms in various cities	No	Yes	±	0	–
7. Pressed wood prefabricated houses; Tablex; Uribe, Bogota, Medellín	No	No	–	0	?

8. Aluminum components; various firms in various cities	No	No	±	0	–
9. Asbestos cement components; Colombia, Manizales; Eternit, Bogota	No	Yes	+	0	+
10. Other lightweight cement components; various firms in various cities	Both	Yes	+	0	+
11. Heavy load-bearing panels; Sigma, Scala, IMC, Estruco, Pretensados de Colombia, Escobar, Okal; Bogota, Cali	No	No	–	–	–
12. Metal houses; ICASA; Bogota	No	No	–	0	–
13. Pressed straw "Cambamit"; Madereras de la Sabana; Bogota	No	Potential	?	?	?
14. Poured ferrocement; Davila; La Dorada	Yes	Potential	–	0	+
15. Plumbing cores; ICT; Medellín	No	Potential	–	0	+

SOURCE: Santiago Luque, "La Prefabricación en Colombia," Centro Colombiano de la Construcción (Bogota: 1971), pp. 8–15.
NOTE: + means favorable; – means unfavorable; ± means favorable in some cases and unfavorable in others; ? means uncertain; 0 means neither favorable nor unfavorable.

and adaptable. Government credit policies should facilitate investments in equipment and large-scale housing projects that are prerequisites of any industrialized building. Government should also train labor for industrialized building, finance prefabrication research, and set up norms and certificates for promoting the use of prefabricated products. Universities, schools, international organizations, and professional groups should undertake complementary measures.[12]

A Study of Cost Reduction

In order to learn more about the possibilities for cost reduction in Colombia, the National Planning Commission organized a detailed study in 1972.[13] Only a few of its findings and recommendations will be noted here. One problem mentioned was the instability of employment that discouraged the organization of training programs for higher labor productivity. This instability was due not only to the necessity of reorganizing work for one site after another, but also and mainly to the uncertain role of housing financial institutions, expanded one year and contracted the next or possibly the year after. When these institutions start building houses directly, the effect is negative despite possibly reduced costs because of the tendency to frighten the remaining private sector.[14]

The commission found that poor coordination had led to an unreasonable diversification in components and materials, which complicated sitework, distribution, and mass production. The report favored promotion of lighter and possibly novel materials with modular dimensions. Imported machinery might have to be subsidized to get production under way. In addition, the government might encourage prefabrication through credit preferences, especially for preinvestment studies, and through its own purchasing policy. Basically, however, the spread of prefabrication would depend on the prior spread of standardization.[15] Except for the modular constraint, designers should not see themselves as working with *given* components, but as ordering components according to function.

Oddly enough, the report did not view the high cost of equipment as a chance for labor intensity but as an obstacle to be met head on. Indeed, it explicitly condemned as a problem "the *a priori* belief that equipment is opposed to a healthy employment policy."[16] The use of equipment, said the report, makes for more agreeable working conditions, helps to overcome bottlenecks, and even "releases resources" for employment generation elsewhere. The apparent and unfounded assumption was that more working capital than labor would be released. The suggestion was to reduce equipment costs through fuller use, possibly with a rental system. Cheaper domestic manufacture was also suggested, where possible.

The problems with labor apparently were seen as more intractable than those with capital. Training systems had a tendency to become obsolete. Intermediate managers for cost control, handling permits, maintenance, work studies, inventory control, and all sorts of manual skills were especially scarce. Poor human relations and inadequate incentive systems caused low productivity. Many of these problems, according to the report, could be avoided with capital-intensive methods because these would foster routinization and eliminate layers of subcontractors.[17]

In a section entitled "Technology" the investigators noted that the best method from a social point of view is not necessarily the most profitable one. Advanced heavy systems were conceded to be inapplicable to Colombia as a whole for the time being. Attempts to advance too abruptly could mean exorbitant adaptation costs. Nevertheless, better planning could lead to continuous-flow building, repetitive actions, mechanization, and standardization of light-weight components larger than bricks or blocks. These possibilities might be explored by a building research center, financed by a percentage tax on construction projects.

Above all, large-scale projects were needed so that design could be "industrialized" as in an automobile industry. (The analogy is widespread but mistaken due to the far more complex and site-bound characteristics of housing.) The experience of one project that involved 200 types of windows was to be avoided. Priority in finance should be given to those projects with modular designs for mass produced components. In line with the trend in other countries and some of the preceding discussion, the report favored "open" systems, ones that can be combined with components from other, presumably also modular, systems.[18] Large-scale projects would also foster programming of sitework, a practice that had begun in Colombia around 1965. Programming had already doubled construction speed in some phases of building Residencias Fenicia, reducing total construction time from 24 to 18 months.

Posibilidades de Reducción de Costos en Edificación

The National Planning Commission report concludes with a number of specific cost-reducing suggestions. If the urban layout is changed and standards are lowered to a minimum, site development costs can fall by 45 percent and total costs by 8.4 percent (not including sales costs and profit, or by 7.2 percent including sales and profit). Of course, these rearrangements and omissions are not strictly technological changes. Since paving constitutes 47–50 percent of the cost of urbanization, the standards and design of streets and walks offer the main chance for savings.

A great opportunity was seen for lowering ceiling-floor costs with prefabricated beams and other components for four- to five-story multifamily housing. These ceiling-floors normally account for 75 percent of the cost of the structural framework (without masonry), which in turn is 30 percent of construction costs, or 21 percent of total costs (with traditional site prices). If prefabrication could lower ceiling costs by 40 percent, construction costs would fall by 9 percent, or total costs by 6 percent.

By not finishing walls and floors, not installing broom closets, and doing no carpentry, much more could be saved: 21 percent of the structure or 15 percent of the total. Omission beats innovation.[19] If these same types of components were not omitted, at least their specifications could be lowered to a minimum. For example, wooden floors cost four times as much as concrete tiles, and marble or carpeting twelve times as much. Painting cement doubles the cost of finishing a wall but remains one-fifth as expensive as a ceramic finish and one-seventh as costly as a wooden exterior. Moreover, all of these and some plumbing fixtures could be completed later.

In general, careful optimizing studies were seen as the best way to reduce costs, implying that common sense, experience, informal communication, and competition were not adequate safeguards against waste. Especially for large-scale projects, appropriate sites could be chosen more carefully and excavated optimally for the right size of structures. The best amount of prefabrication could then be specified for multifamily buildings. Scientific choice of insulation, roofing, floor materials, open spaces, plumbing, electrical systems, and finishes could all "appreciably" reduce costs. The expense of these studies per unit would itself fall by one-third if 1,000 instead of 50 dwellings are planned.

Apart from the structure (especially ceiling-floors), prefabrication was thought possible for walls and fixtures. Small components such as lintels and stairs might be involved, eliminating the waste of cutting on the site. Greater standardization would necessarily be involved in these operations. In other words, the experience of ICT and the findings of Luque ·ere to be followed.

Labor and equipment could be used more efficiently, apart from design changes, in site preparation, foundations, and above all, in plastering. Throughout, management could be better, from organizing the site at the beginning to cleaning it at the end, or even preventing the need for much cleanup. Inefficient purchasing and inventory methods were in some cases believed to double the cost of materials.[20]

The study concludes with a summary statement that rationalization clearly offers "much greater" cost-reducing possibilities than technological improvements. Rationalization, say the authors, is primarily a question of institutional change, and it requires less investment than technological change. This conclusion appears more conservative than earlier pages about the benefits of large-scale projects.[21]

Residential Density, Labor Intensity, and Building Costs

The possibilities for extensive systems building are limited in Colombia because the abundance of labor and the need for employment will keep traditional single family housing more economical than any other type. Among multifamily dwellings, those with four to five stories can be built more cheaply than those with 12 or 30. Systems building can reduce costs the most for high-rise dwellings, but not conceivably by half, the amount needed to make high-rise construction competitive with conventional low-rise dwellings. The site costs of lower density do not offset lower construction costs until the price of land (without improvements) rises from 30 percent to 54 percent of the single family housing price, excluding sales costs.

The most expensive components of a dwelling are also those with more technological alternatives in construction. These are the foundations, the structural framework, masonry, roofing, floors, plumbing, carpentry, and fixtures. As can be seen in Table C3, these came to about 72 percent of single family housing costs and 65 percent of 12- or 30-story apartment costs. These figures are based on actual cases of conventional construction in 1971.

The share of labor in construction costs falls from 31.5 percent for single family housing to 25.8 percent for 30-story apartments, as shown in Table C4. Nevertheless, high-rise dwellings use more labor per square meter: 39 instead of 18 man-hours (Table C5, line 18). The lower share of labor was not due to the use of less skilled workers or paying lower wages since the average wage paid per man-hour (including fringe benefits) was one-tenth higher in apartment building. The lower share was due to higher nonlabor costs that doubled construction

Table C3. ***Share in Construction Costs of Components of Dwellings, Colombia, 1971***

	Single family			*Multifamily*	
	One story (percentage)	*Two story (percentage)*	*4–5 stories (percentage)*	*12 stories (percentage)*	*30 stories (percentage)*
Foundations	7.5	6.0	3.7	5.4	7.7
Structural framework	—	10.9	20.0	25.4	34.5
Masonry	19.6	15.9	7.2	6.1	2.9
Roof	12.1	7.9	1.4	0.4	—
Floors and closets	9.2	9.7	11.5	6.8	5.0
Plumbing	16.6	13.4	12.2	12.1	7.8
Carpentry and fixtures	7.8	8.6	13.5	8.7	7.6
Subtotal	**72.9**	**72.4**	**69.5**	**64.9**	**65.5**
All others	**27.1**	**27.6**	**30.5**	**35.1**	**34.5**
Total	100.0	100.0	100.0	100.0	100.0

SOURCE: Departamento Nacional de Planeacion, *Posibilidades de Reducción de Costos de Edificación* (Bogota: November 1972), vol. 2, Table 6.6.

NOTE: Taxes, insurance, contingencies, and design costs have been omitted. Design costs were 10 percent of the larger total for single family dwellings, 11 percent for 4–5 storys, 11.8 percent for 12 storys, and 12.5 percent for 30 storys.

Table C4. ***Share of Labor Costs in Selected Components of Dwellings, Colombia, 1971***

	Single family			*Multifamily*	
	One story (percentage)	*Two story (percentage)*	*4–5 stories (percentage)*	*12 stories (percentage)*	*30 stories (percentage)*
Foundations	30	35	30	10	15
Structural framework	—	28	25	20	20
Masonry	35	35	35	35	40
Roof	25	20	20	15	—
Floors and closets	25	25	25	20	19
Plumbing	20	25	25	25	25
Carpentry and fixtures	**15**	**12**	**12**	**10**	**10**
Total cost	31.5	31.4	29.7	26.8	25.8

SOURCE: Departamento Nacional de Planeación, *Posibilidades de Reducción de Costos de Edificación* (Bogota: November 1972), vol. 2, Table 6.6.

Table C5. *Land and Construction Costs of Colombian One-Story Single Family and Multifamily Four- to Five- and Thirty-Story Structures, 1971*

Item	*One-story single family*	*4–5 story multifamily*	*30 story multifamily*
1. Number of units	1	20	120
2. Net density of settlement	67	133	400
3. Square meters of land needed per dwelling	150	75	25
4. Price of land per square meter, U.S. dollars[a]	7.15	7.15	7.15
5. Cost of infrastructure per square meter, U.S. dollars	3.81	2.29	1.91[b]
6. Cost of site per dwelling, U.S. dollars	1,643	707	227
7. Area of floor space, square meters	90	90	90
8. Construction cost per square meter, U.S. dollars[c]	42.86 (38.10)	61.91 (71.43)	85.71 (114.29)
9. Construction cost per dwelling, U.S. dollars	3,857	5,572	7,714
10. Total cost of site and construction, U.S. dollars	5,500	6,279	7,940
11. Ratio to single family dwelling cost	1.00	1.14	1.44
12. Share of site in total percentage	29.9	11.3	2.9
13. Percentage rise in site cost, all other things being equal that make total cost equal to single family cost	—	145	273
14. Implied price per square meter of land (without infrastructure)	—	16.09	24.47
15. Implied share of site in total cost of single family dwelling, percentage	29.9	45.4	54.2
16. Assumed sales cost at 20 percent, U.S. dollars	1,100	1,256	1,588
17. Price, U.S. dollars	6,600	7,534	9,528
18. Labor as a share of construction costs, percentage	28.7	25.7	23.8
19. Man-hours per square meter	18	29	39

SOURCE: Departamento Nacional de Planeación, *Posibilidades de Reducción de Costos de Edificación* (Bogota: November 1972), vol. 2, pp. 202–11.

[a] U.S.$1.00 = 21.00 pesos, 1971.

[b] If the site were 1,500 square meters, cost would be $3.50. In general, the infrastructure costs appear too low for the multifamily structures. They should be lower per dwelling but not per square meter.

[c] Figures in parentheses are alternative estimates for different standards.

costs from US$43 to US$86 per square meter (Table C5, line 7). The labor intensity of low-rise construction, while good, is not its principal advantage from the point of view of costs. Even for economical apartments, high-rise building requires more reliable and expensive materials and peripheral expenditures that can be omitted in single family housing.

How the share of labor falls as the number of stories rises can be seen in Table C4 for the major building components. Foundations for single family housing have a labor share of 30–35 percent, for high-rise apartments only 10–15 percent. The walls of one-story houses are masonry with a 35 percent labor content; those of high-rise apartments are mainly a reinforced concrete framework with only 20 percent labor. For high-rise as compared to one-family dwellings, the labor content of roofing and flooring falls from one-quarter to less than one-fifth; that of carpentry and fixtures from 15 to 10 percent. Only plumbing is less labor intensive for one-story housing and constant for all other types.

The principal cost disadvantage for single family housing is its greater use of land or lower density of settlement. If land costs US$7.15 per square meter, and if density of settlement is one-sixth that of high-rise apartments, then the cost of the site per dwelling would be US$1,643 compared with $227. As a share of the total, the site would come to 30 percent instead of 3 percent (Table C5, rows 5, 11). Nevertheless, high-rise apartments still cost 44 percent more than single family houses, and four- to five-story apartments would cost 14 percent more.

With increasing urbanization, the price of urban land will rise faster than the rate of inflation because of changes in accessibility. For sites that have risen more than 145 percent in constant value pesos, four- to five-story apartments will become cheaper than single family housing, for which the share of the site would then have risen to 45.4 percent of total costs. The constant peso price would have to rise by 273 percent, bringing the land share to 54.2 percent, before 30-story high-rise apartments are as economical as single family housing.

Since land values in Bogota seem to have risen by no more than 2–3 percent in real terms in the past dozen years, 30–45 years must pass before the value of new land has risen by the 145 percent in real terms, or enough to make single family housing submarginal. Sites near new employment centers and transportation routes will obviously rise faster. The implication is nevertheless very strong that nothing beyond four- to five-story apartment buildings should have a role in Colombian low cost housing.

Technological Policy Recommendations

This section will present only policy recommendations that have already appeared elsewhere. One set came from the Inter-Agency Mission on Employment Strategy, organized by the International Labour Office and led by Dudley Seers in 1970. This group favored a labor-intensive role for construction and projected no more than a 1.4 percent annual rise in labor productivity for 1970–1985, together with an incremental capital-output ratio (ICOR) of 1.8 to 2.3. By contrast, sectors such as modern manufacturing were deemed to have an acceptable ICOR around 4.5 and a labor productivity rise of 4 percent annually. The group feared that building mechanization had "irreversible consequences," that it could lead to a rigid employment structure, meaning the loss of the subcontracting and sub-subcontracting systems, "one of the best cushioning devices in the Colombian economy." Without it, wages could rise by 50 percent, but employment would fall in greater proportion. Moreover, any temporary shortage of skills could be overcome easily.[22] The mission recommended that

> moderate hurdles should be placed in the way of mechanization in construction, to ensure that the construction boom which is feasible yields its full potential impact on employment. . . a builder with novel systems could be prohibited from revising contract prices upwards in the course of construction for any reason whatsoever. If his system is really better, fine. But the public must be protected from having to bear the gamble and learning costs of its development . . . . Permits can be withheld from projects using a socially undesirable level of mechanization. For the optional piece of equipment, one could make construction firms show that its "social" cost is less than its "social" gain. Labour savings (appropriately measured), together with any savings in interest charges due to faster construction, must be shown to outweigh the depreciation and interest on the extra capital added to the change in material costs.
>
> We suggest that depreciation allowances on *equipment* should not be allowed as a deduction against taxable income . . . . (It would be necessary of course also to disallow fees or rents for the hire of such equipment.) . . . Depreciation allowances on *buildings* however, should continue as before, otherwise the necessary expansion of construction (which is labour-intensive) will not be achieved.
>
> This line of thought suggests the possibility of allowing a premium to be added to the wage bill before the latter is deducted from sales proceeds to arrive at taxable income.[23]

The mission was aware of the employment-discouraging effect of rising land prices; for this reason, as well as for more rational city planning, it recommended greater powers for government to expropriate urban land with fair compensation.[24]

The new government of President Misael Pastrana did give housing first priority during 1971–1974 but without the technological measures recommended by the ILO mission. Reflecting the view of Lauchlin Currie, some members of the government felt that employment generation with low productivity rises was a "static" approach.[25] The important thing was to change the structure of the economy, with residential building as a leading sector. What mattered was to get the system going, break bottlenecks, build housing, and generate savings. In 1973 a leading spokesman for the government told me: "About technology, we don't care one way or the other." But since capital-intensive technology will not flourish in Colombian house building without deliberate government support, I did not find that mechanization or prefabrication had made undue progress since my earlier visits in 1968 and 1970.

Meanwhile, the Colombian government, the World Bank, and the United Nations Development Program had engaged a large group of consultants to make an "Urban Development Study" for Bogota. Its work was finished in September 1973. The group concentrated on developing new employment centers, adequate social services, especially a better transportation network, and a suitable density of settlement for 1980 and 1990.

Although choice of technology was not a central concern for the group, its recommendations did not fit high-rise, capital-intensive systems building. According to its proposals, about one-fourth of the 1980 population, or 207,000 households, would live in new areas. The density of settlement sought would put 60 percent of households with annual incomes between US$1,000 and $2,600 in four- to five-story apartments at a density of about 130 per hectare. Only 25 percent of households receiving over US$2,600 would be in such apartments. The remaining households of these two groups would be largely in two- or three-story row housing at a density of 35–50 per hectare. Five to 10 percent would have individual lots. The poorest third of households in new areas would be settled at a density of around 70 per hectare.

These densities and housing types were a solution that reflected a variety of pressures. One of these was the widespread desire to own a house. Of all people wishing to change their dwelling, 89 percent favored house ownership, while only 9 percent wanted to rent a house, and only 2 percent preferred an apartment. Important in this preference among poorer groups was the chance of adding on, of subletting a room or two, and of setting up a shop. Relations with neighbors were also much better in houses than in apartments.

Alternative costs also mattered. The study group concluded that construction costs per square meter in twelve-story blocks would at least be 20 percent above that of four- to five-story apartments and more than double that of two-story houses. Since the reasonable upper limit for net residential density — 150 dwellings per hectare — could be achieved without exceeding four to five stories, as in the Pablo Sexto Development, twelve-story apartment blocks were ruled out as a general pattern.

Moreover, good quality apartments even in four- to five-story buildings, and even if only 50 square meters in size, simply could not be provided for all Bogota by 1980. If the square meter construction cost were to be a plausible US$75, or US$4,500 per apartment including site costs, the housing subsidy alone would have to be over half of Bogota's gross output, or twelve times the level of all other probable public expenditures combined.

In the early 1970s, 70 percent of housing was built outside the system of zoning and controls. The study commission considered it of prime importance to bring such spontaneous development within the legal planning framework. The minimum possibility was to give each family a ten-square-meter core dwelling on a 65-square-meter lot with a latrine and serviced by a tarred road. Water would come from public fountains. The cost per site would be around US$500, and by 1980 the implied subsidy to families who could not afford even that would be nearly US$2 million per year, or somewhere between one-fourth and one-third of the resources that government could channel toward housing, directly or indirectly. For about a quarter of the households moving into new areas around Bogota, therefore, the appropriate technology would remain the bricks and boards that the owner could add to these cores in his own way.

Summary

The experience of Colombia with housing technology can be a guide to other countries seeking to improve incomes, employment, and urban standards. Not only has the country tried a number of different building methods and financial systems, but also its experience has been analyzed by various national and international groups of experts with somewhat different points of view and priorities. Their interpretations and recommendations are available and can be compared with circumstances elsewhere.

The widespread fascination of architects and engineers with prefabricated, modular, and industrialized systems building was not lacking in Colombia. Numerous attempts were made to introduce such methods but almost invariably with discouraging results. Exceptions were mainly ways of making the intermediate floors of multistory buildings with prefabricated beams or formwork. Compared with conventional labor-intensive, subcontracted construction methods, costs of other industrialized methods were either too high or quality too low. The ultramodern methods were most viable in high-rise apartments, but most Colombians had an aversion to living that way, and pressure for optimal densities or rising land prices did not have to push them into such buildings.

Low-rise buildings were not only cheaper per square meter, but also more labor intensive, a characteristic stressed by the ILO mission. The best way to lower costs, found the National Planning Department, was to lower the quality of some finishes or to omit them altogether, as well as to rationalize the manufacture and specification of conventional components so that these could be mass produced. The UN–World Bank financed group limited itself to Bogota and sought ways of keeping that city an efficient unit while its population triples by 1990. For the time being, they concluded, resources would remain insufficient to build complete houses for a large fraction of poor people, so that self-help technology, more or less crude, would continue to be an important part of building. Such urban growth should nevertheless be planned with faith in later resurrection and transfiguration.

Appendix D

Innovations in Building Methods and Employment in Puerto Rico

Innovations in Building Methods and Employment in Puerto Rico

Much can be learned from housing experience in Puerto Rico, an island that has been in an intermediate zone on the development trajectory. Per capita product rose from $441 in 1940, to $1,040 in 1960, and to $1,881 in 1972 (1970 U.S. dollars). Insofar as its economy can be compared with others, one might call it a decade or two behind highly industrialized nations and a decade or two ahead of most of Latin America. Atypical, of course, are Puerto Rico's special incentives to U.S. manufacturing investment and corresponding special access to the U.S. market. But construction is not subject to this type of international arrangement: Dwellings must be built mainly with the island's factors of production and for island residents.

What matters most is that the government has stressed residential construction, raising its share of GNP from a high 5.2 percent in 1960 to an average of 8.3 percent during 1965–1970. For most countries the share has been between 2 and 5 percent. Over half of the long-term funds for this program came from the United States through private and public channels. Meanwhile, construction wages, including fringe benefits, had risen to $2.20 per hour by 1972. Modernization of construction methods was not only welcomed, but also actively promoted by the government. Any innovation that failed or was barely marginal under these favorable conditions should be avoided or tried skeptically by poorer countries with lower wages and less capital.

Economic Trends and Housing in Puerto Rico

Puerto Rico has 8,928 square kilometers and 3 million people. It is a self-governing commonwealth, or "Free Associated State," that pays no U.S. taxes, has no vote in the U.S. Congress (except in committees), but participates in virtually all U.S. expenditure programs.

The island's high rate of economic growth dates from the late 1940s, when the government sold a number of its manufacturing plants and used the proceeds and tax exemptions to attract U.S. investment. Gross fixed investment soon exceeded one-fifth of GNP and reached 26 percent by 1965–1970. The emigration of 450,000 people during the 1950s held the rate of population growth down to 0.6 percent in that decade. The birth rate fell from 3.4 percent in 1960 to 2.4 percent by 1971, but since emigration fell to 165,000 during the 1960s, the rate of population growth rose to 1.3 percent.

The demand for housing was, as always, affected by the condition of the dwelling stock, rising incomes, internal migration, and the net rate of household formation, which rose from one percent during the 1950s to 2.4 percent during the 1960s. Due to internal migration the nine municipalities of the San Juan area grew from 563,000 inhabitants in 1950 to 956,000 in 1970. Many of these migrants moved into decaying and slum areas. The number of inadequate urban housing units (by U.S. standards) was estimated at 110,000 out of a total occupied stock of 632,000 in 1970 and seemed likely to grow to 142,000 by 1980.[1]

The Puerto Rican building program brought the number of dwelling units from 222 per 1,000 people in 1960 to 263 in 1970, or to the approximate level of Poland (258) or Bulgaria (270), in pure numbers. Of course, Puerto Rican quality was high, with the average new house, insured by the U.S. Federal Housing Administration (FHA), having 88.11 square meters, 5.2 rooms, more than one bathroom, and a value of $15,000, not including the site. But the stock remained far below the 401 per 1,000 of Sweden or the 376 of France and Denmark. The rate of building, however, averaged 7.1 units per 1,000 population during the 1960s and temporarily rose to 9.5 units around 1970. This rate is close to the UN target of ten per 1,000 and far above the one or two per 1,000 typical of developing countries. In Europe it was exceeded only by Sweden (13.6), Greece (13.0), Switzerland (10.5), and Denmark (10.3).[2] The rate was temporarily good, but rising costs and the need to reach the lowest income families (the population group which felt the remaining housing deficit) sustained interest in low cost industrialized building innovations.

Housing Policy

The government has reinforced private industry in housing by engaging in design, finance, supervision of construction, and even owning and management in a wide variety of programs, both local and federal. Much housing financed by private institutions had government (FHA) insurance. In terms of units started, those to be owned and rented by the government constituted 34 percent of new housing in 1961 – 1962 but only 20 percent in 1971 – 1972. A federal program, suspended in early 1973, not only subsidized interest payments above one percent, but also included rent supplements in private housing and urban renewal projects. During 1970 – 1972 the average number built annually with such federal help amounted to 8,100 units.

The government sponsored or financed an additional 7,850 units per year. The P.R. Housing Bank, established in 1962, lends to low and moderate income families, and its deficits are made up by the legislature. The P.R. Land Administration, also set up in 1962, is supposed to acquire land reserves for publicly sponsored building. The Cooperative Development Administration occasionally acts as its own contractor in addition to sponsoring "turnkey" projects by builders. Finally, there is the Urban Renewal and Housing Corporation (CRUV), set up 1958 to consolidate a number of earlier programs and housing authorities.[3] In 1973 all of these were integrated into a Department of Housing.

Innovations have been primarily sponsored by CRUV and its research and planning counterpart, the Urban Renewal and Housing Administration (ARUV). Before ARUV, however, came an attempt in the 1950s to introduce 500-square-foot concrete shell houses with self-help and mutual aid methods. Technical assistance and interest-free loans of $800 – $1,000 for ten years were given. In the late 1960s an average of 2,400 houses were still being built under this program in rural areas, but after completing 153 units, the mutual aid approach to urban housing was discontinued.[4]

Next came the "Core House" of 1961. CRUV would build the foundations, columns, and roof (or the entire shell and plumbing), and the owner would finish the house on his own. For lot and core, he would borrow and repay about $2,500 in up to 30 years. Under this scheme, 834 units were built. Note that in Puerto Rico a genuine sites-and-services program dates back to 1947.

Finally, in 1969 came the "Basic House" or "Modest House" program that is supposed to develop structures worth $3,000, including kitchen and bath. If $1,500 is added for the lot, the price comes to one-third of a more conventional Puerto Rican low cost house.

In the meantime, however, the government's preference was shifting away from single family housing. Land seemed to be too scarce for such low density development. Should the entire island become one urban settlement? As early as 1962–1963 the Planning Board imposed a temporary freeze on all new construction while working out better regulations for new subdivisions. Especially for the San Juan area, planners thought that if permits were given more readily for multifamily-multistory housing, tastes would change to accept what was available. The trick was not to be voted out of office first. As an angry reader wrote to the *San Juan Star* (18 July 1973): "They finally have built larger boxes of cement with the subsequent crowding of all facilities in the community and . . . assault of the few quiet and nicest places still available in the metropolitan area to raise a family or is it something wrong to have a quiet unpolluted place to raise your children? Does everybody in Puerto Rico have to live in such conditions, that by adequate standards are 'ghetto-like' even if you can afford something better?"

A more direct educational campaign in favor of multifamily housing was proposed.[5]

A section designated the Experimental Program of Industrialized Housing was set up within ARUV. This program coincided with a desire to explore industrialized housing in the United States by the Department of Housing and Urban Development (HUD) and "Operation Breakthrough." Thus ARUV was able to carry out its innovative explorations with the help of a substantial federal grant. The objective was to promote cheaper housing, not employment, although throughout the 1950s and 1960s, 11–13 percent of the Puerto Rican labor force was openly unemployed. Not all of these were potentially suitable or available for construction, and, indeed, there was a shortage of certain skilled building trades. A survey showed that over 90 percent of firms complained about a shortage of bricklayers, carpenters, and, to a lesser extent, electricians and plumbers. These activities also had a comparable shortage of subcontractors, as an obvious result.[6]

Some planners worried about the possible employment effects of industrialized building systems, but no study of these effects was ever made. Expanded training programs were recommended, but capital-intensive building was the preferred solution and more in line with a preference for high capital intensity throughout the Puerto Rican development strategy. Capital-intensive manufacturing industries were less vulnerable to the pressure of rapidly rising wages, that is, less likely to migrate back to the mainland after using up their tax exemptions.

In sum, government planners feared that housing conditions on the island would grow worse because some direct costs were rising faster than family incomes. They claimed that a steadily smaller share of families would henceforth be able to afford a new dwelling. Also rising was the indirect cost to society of using the dwindling supply of land at low density.

Since raising incomes or capital on easy terms was difficult, the Planning Commission reaffirmed in 1971 that the rise in building costs and use of land had to be slowed down. Needed was "an aggressive policy to promote the use of prefabrication and of industrialized dwelling construction." The commission called for a quasi-public Construction Institute to study novel building methods, enlighten the industry, and coordinate plans with a permanent new government office for industrialized housing. Tax reductions or other incentives should be given to builders who led the way toward lowering housing prices with new technology.[7]

General Characteristics of the Puerto Rican Building Industry

A sympathetic climate for innovating is not only a matter of demand by occupants and government housing policy, but also one of the structure of the building industry, or supply. In Puerto Rico the most striking feature is concentration or dominance by two dozen large builders. These not only construct most of the island's multifamily structures, but also about half of its individual units. In the larger cities, these twelve built about nine-tenths of the dwellings in 1970–1971.[8] Medium-sized builders (50–250 units per year) constructed about one-quarter of the single family units, and small builders the remaining one-quarter. In 1970, single family units accounted for 68 percent of building starts in San Juan and 89 percent elsewhere.

This concentrated industrial structure is conducive to those innovations that depend on volume. However, the competitiveness of mechanized building did not itself cause the high degree of concentration; in 1971, 86 percent of firms neither used, nor planned to use, prefabricated structural components. What mattered more were the economies of scale in grading and draining the Puerto Rican topography. Vacant land that does not need much investment of this sort is scarce and expensive in Puerto Rico, and therefore the financial capacity to buy large tracts is crucial. Even with these scale economies, the 1970 average price per square foot of land for FHA-insured houses was $1.57, compared with $0.81 for the United States. Even though building lots averaged less than half as large in Puerto Rico as in the United States, the share of the site in the market price of FHA-insured housing was higher, 29 percent compared with 21 percent in the United States.

The higher Puerto Rican percentage for the site was not due to any lower cost for an equivalent structure. On the contrary, construction costs were estimated to have been 10–15 percent higher than U.S. costs. Since quality can, in fact, be lower in Puerto Rico (wooden shutters instead of glass windows), the actual average price per square foot was only about 5 percent higher than in the United States.[9] But this quality has been improving; for example, over 60 percent of single family houses are now being designed with two or more bathrooms.

One study of Puerto Rican building assumes that, compared with the United States, it is reasonable to adjust employment needs upward "by 10% for low productivity due to local labor conditions.[10] Another asserts that costs outside San Juan are 10–15 percent higher "due to a generally slower construction pace, lack of skilled labor, the absence of local backup services, and a lower annual volume."[11] A certain amount of fatalism about such low productivity and lack of skill, together with expectations of rising wages and the need to build large volumes, has added to the predisposition in favor of mass production methods.

Experience with Unconventional Building Materials

Apart from the self-help and core houses promoted by the government directly during the 1950s, an early attempt at innovation was the IBEC form invented by Wallace Harrison. This form was a single metal mold for an entire two-bedroom house. Roofs were precast on the site in a separate bed and lifted into place with a crane. These molds did not, however, allow variety in appearance or floorplan, and an unexpectedly long curing time raised the capital cost per unit. After the attempt was abandoned in Puerto Rico, the molds were sent to Chile for a second (unsuccessful) attempt at introduction.

From this beginning, IBEC (International Basic Economy Corporation) moved in two directions. Experience with the metal forms led to the adoption of the more flexible French Outinord system of "tunnels," described in chapter 6. As are the similar Feran and Stehm systems, Outinord is in successful use in Puerto Rico, although sufficient forms for producing two dwellings per day cost about $300,000 and must be repaired extensively every year. The other IBEC development was a system of on-site prefabrication of heavy panels for one- and two-story single family houses. This system also remains in use in Puerto Rico, and it provided the experience that led IBEC to participate in the founding of the high-rise building consortium, RELBEC. Altogether IBEC had built over 13,000 houses in Puerto Rico by 1973.

Apart from IBEC, RELBEC consisted of the Rexach Construction Company, the largest prime contractor and developer in Puerto Rico, and of Larsen and Nielsen Consultor, who promote the Danish building system of that name throughout the world. In addition to the Danish horizontal, automatic panel casting, the RELBEC "Core-Pack" system employed the American Spandec approach of posttensioned floor slabs (that can be sawed to size) and a British vertical battery casting machine with steam curing. Cement was poured into the Danish forms from a buggy on a monorail and was smoothed with a German automatic device, eliminating trowelling. The finish was nearly perfect, and windows, plumbing, and electrical systems were fully integrated into the ten-ton panels.

Altogether, the plant cost $6.4 million and employed 125 mostly unskilled workers. The investment per worker was $51,000. Larsen and Nielsen said, however, that plants costing several million dollars less were still feasible. One of these was being considered in Trinidad. For an eight-hour shift the volume of the Puerto Rican plant was 1,500 dwelling units per year, but transport costs dictated that these must be constructed within a radius of 50 kilometers. An additional shift could be undertaken by investing in additional storage space. A two-shift volume of 3,000 units per year would equal one-third of the multifamily volume of construction in the San Juan area during 1965–1969 and about one-sixth of that projected for the 1970s. Minimum economic volume for a given style was either 500 or 200 units per site; one minimum depends on the cost of molds, the other on that of installing cranes. The labor content of the final structure is said to be only 3 3 percent.

The factory was built in about two years and opened in May 1972; it contained a section for market studies and technical design and one for construction. For a specific new housing project, delays associated with ordering molds and materials require a long lead time in company planning. Approval of designs by separate government financial and planning institutions is also time consuming, and if it is delayed more than six months, serious trouble can result. The high capital investment and the fixed storage and production capacity mean that trying to operate either beyond or short of full capacity causes losses. Flexibility in the form of time or variable costs is low. Nevertheless, since the various governmental boards and commissions that must approve and which, like CRUV, may even be the ultimate owners are in separate organizations and parts of the city, delays are common, and the company must know how to plan for these in terms of ordering in advance and making other commitments without risk.

By December 1975 RELBEC was ready to sell its plant to the government, which refused to buy or to guarantee purchase of 1,000 dwelling units annually. RELBEC declared bankruptcy and closed the plant.

Failures and Poor Prospects

Conspicuous among the failures have been attempts to build with prefabricated modular boxes, which, for a time, were thought to be even more advanced than load-bearing panels, that is, closer to the ultimate industrialized way of building. Actually, they were more of a step backward to the 1950s and the IBEC molding-form for an entire house. Once more, in Puerto Rico as on the mainland, it had to be learned that more complex is not necessarily cheaper or better, although obviously more inflexible. RELBEC promotional materials stress that some inflexibility is good: "Because every detail must be planned ahead of time, costly alterations during construction are almost completely eliminated."[12] But when planning is imperfect, the possibility of adaptation during construction can lower costs.

"Uniment," a system of half-boxes incompletely finished but with integrated subsystems, was an intermediate approach, promoted by Stressed Structures, Inc., of Littleton, Colorado. The method was considered but not tried in Puerto Rico, apparently because the authorities had doubts about the "Chemistress" concrete expander that gave the modules their light weight. In modular boxes, reduced weight is crucial to prevent the cost of stronger cranes from offsetting labor saved by not having to join panels.

Another attempt was the "Modular Housing System" of the Development Corporation of Puerto Rico. Hundreds of units were produced at the rate of two units per day at a plant in Carolina, near San Juan. Some of these were shipped by barge to St. Croix, Virgin Islands.

The spectacular failure, however, was that of Shelley Enterprises because their system had received much publicity at the "Vivienda 70" exposition. In this system of open-ended boxes made on-site, weight was reduced by one-sixth through lightweight aggregate in the cement. The boxes were stacked in a checkerboard fashion, so that about half of the enclosures were obtained "free." For stability the whole was post-tensioned with tightening cables going through the corners of all boxes from one story to all others. Although problems with the posttensioning arose, the principal difficulties were economic and organizational. Ten to 25 percent savings had been expected at a middle not low cost level of design. But, for a highly capital-intensive operation with inexorable fixed payments, such as Shelley's, delays in obtaining permits after installing equipment, and further delays due to an excessive rainy season, were fatal.

In general, industrialized building was expected to be 10–25 percent cheaper than conventional construction for multifamily, and above all high-rise, housing in Puerto Rico. For single family housing, the most that was claimed was that costs would be about equal to conventional methods, and even that estimate was optimistic. The Planning Office of the Puerto Rico Urban Renewal and Housing Administration surveyed these and other proposed systems, and the results are given in condensed form in Tables D1 and D2. Note the heavy equipment that is required and the high minimum volumes.

The ARUV-Estiot Study of Industrialized Building Costs

After surveying the existing and proposed industrialized building systems, the Planning Office of ARUV began a detailed study of an innovative housing system that might be tried promptly in Puerto Rico. The initial impulse was to develop something novel that "should reflect the Commonwealth's situation rather than the practice in other countries."[13] But the orientation soon became more conservative: "The way to make the most progress in furthering industrialization in housing is to depend to a great degree on systems which have been well-proven elsewhere."[14]

The system chosen as the basis for estimates was that of the decades-old French firm, Estiot, which supplied cost details. As the project matured, additional advice came from Bohdan Lewicki of the Polish Institute for Construction Techniques. The Puerto Rican group

Table D1. *Some Characteristics of Industrialized Multifamily Housing Systems in Use or Considered for Use in Puerto Rico, 1971*

System	*Description*	*Equipment*	*Minimum volume*	*Cost claimed relative to conventional*
Relbec, based on Danish Larsen and Nielsen, Spandec, and vertical batteries, in use in Puerto Rico	Ten-ton panels, highly finished at central factory, integrated windows and subsystems	$6.4 million factory; heavy transport and cranes	1,500 factory 200 crane	n.a.
Shelley modular boxes, "Vivienda 70" of Operation Breakthrough	Boxes (25′ x 18′ x 11′) of lightweight aggregate concrete, stacked in checkerboard pattern and postensioned	Onsite factory with heavy gantry cranes	700	10–25 percent less expected, but failed
Modular Housing System, Development Corporation of Puerto Rico, contracts in Puerto Rico and St. Croix	Existing Puerto Rican factory made fully finished lightweight concrete modular boxes; postensioned five-story limit	Central factory, heavy trucks and cranes	n.a.	n.a.
Estiot, a French system widely used in Europe and Algeria	Off- or onsite factory for heavy floor and wall panels located with lightweight steel structure; integrated subsystems, plumbing, and so forth	$500,000 factory; 30-ton trailers, cranes	240–300	15–25 percent less

Balency, French system, widely used in Europe	Offsite factory except for largest projects; heavy panels but *in situ* floor; functional blocks hold subsystems	Automatic table and battery casting, 30-ton trailers and cranes	500	10–12 percent less
Coignet, French system widely used in Europe, some in Argentina, Brazil	Automated factory makes heavy floor and wall panels, highly finished, integrated subsystems	$2 million factory and 10-ton lifting equipment	1,000	10–20 percent less
HISA-Precasa, Spanish system	Heavy floor and wall panels	Heavy	n.a.	n.a.
Tracoba, European and African experience	Heavy floor and transverse wall panels, nonload-bearing facade panels, cast at plant or onsite; little subsystem integration	Metal battery molds, 30-ton trailers and cranes	500	15 percent less
Uniment by Stressed Structures, Inc. FHA approval and six-story prototype in California	Monolithic, lightweight, modular half-boxes, finished onsite; integrated subsystems	Large casting molds and 15-ton cranes	n.a.	Uncertain

SOURCE: Experimental Program of Industrialized Housing, Planning Office, Puerto Rico Urban Renewal and Housing Administration, *Industrialized Housing Systems for Puerto Rico: A Survey of Construction Methods for Programs of Social Interest* (San Juan: April 1971), pp. 28–58.

Table D2. ***Some Characteristics of Industrialized Single Family Housing Systems in Use or Considered for Use in Puerto Rico, 1971***

System	*Description*	*Equipment*	*Minimum volume*	*Cost claimed relative to conventional*
IBEC panels, in use in Puerto Rico since mid-1960s	Panels (load-bearing) poured at onsite factory; simple welded connections	30-ton trailer, steel molds	n.a.	n.a.
Novoa, light posts and panels, approved by HUD and Planning Board	Onsite precasting of panels that slide into grooves on posts that are also site-cast; no skills needed	Light crane and molds	"low"	5 percent less
Pacadar panels, approved by Planning Board	Site-poured panels are postensioned; electricity and plumbing in floor	Molds, crane	200	Equal
Panel-Lock of Lockheed Aircraft Service, approved and used in Puerto Rico	Offsite factory for aluminum framed panels; joined with bars and metal clamps; poor insulation	Heavy trailer and crane molds	n.a.	Similar
Panelfab International, approved by HUD and Planning Board, used for schools	Light factory-made panels of metal skin around honeycomb kraft paper, steel columns	Special for production but not erection	500	"Significant savings," but failed
Simalva-163 of Simon and Alvares, approved by Planning Board	Onsite prefabrication of large concrete elements, conventional plumbing and electrical system; stability through shape, not mass	Molds, medium-size crane	n.a.	About equal
Uniloc Systems, approved in California, Florida	Offsite factory for aluminum framing, lightweight masonite or gypsum panels; connected with snaps or pins	Extrusion plant, transport	500	Uncertain

SOURCE: Experimental Program of Industrialized Housing, Planning Office, Puerto Rico Urban Renewal and Housing Administration, *Industrialized Housing Systems for Puerto Rico: A Survey of Construction Methods for Programs of Social Interest* (San Juan: April 1971), pp. 28–58.

was cautious about volume and aimed at a minimum of only 300 units annually, not the 13,000 units of the Russian Koslov system. They realized that insistence on architectural variety by potential occupants might become a problem as family incomes rose. The group was also conservatively willing to leave some finishing and some electrical and plumbing installation for sitework and subcontracting.

The result to be obtained with the Estiot System was 17 percent cheaper per square foot of area than the average cost of FHA-insured single family homes built in 1970: $12.76 instead of $15.39 per square foot (not including land). The average FHA house, however, aimed at a higher income level and offered not only 20 percent more space, but also higher quality for its 46 percent higher total housing price. For an apartment of comparable quality, the unit cost advantage of the new therefore might be less. If the factor prices of typical developing countries are used — twice as much for capital and one-quarter for labor — then the advantage of the industrialized approach falls to less than 5 percent, if it remains at all. Moreover, the Puerto Rican authors warn that, "for a 'first time' project, one must increase these estimated costs, based on purely subjective considerations, by adding 'unforeseen' costs to certain items that may be considered more risky by a particular 'entrepreneur.' "[15]

Before discussing various costs, the general specifications should be explained. Four-story buildings were designed with six apartments per floor, placed parallel to one another so that a single construction crane and set of outside stairs could service two buildings. Outside galleries were to give access to the entrances of the apartments so that almost all of the 19,500 square feet of building space would be available for private use. Average area per apartment was to be 810 square feet. Including galleries and stairs, a building would consist of 320 panels, with an aggregate (single-face) surface of 1,370 square feet, made up of 740 cubic yards of concrete. The design was such that *in situ* pouring of concrete with the Outinord, Feran, or Stehm metal formwork system was a possible alternative.

Quality was to equal U.S. federal minimum standards with respect to closets, storage facilities, plumbing, and so forth. Floors were to consist of integral or asphalt tiles. Vinyl could be substituted. Each unit was to have a kitchen-dining area and a service patio protected by ornamental concrete blocks, both reflecting Puerto Rican living patterns. All rooms were to have cross-ventilation, and the four-bedroom apartments would have two bathrooms.

The cost estimates assume that the site is level and has adequate access for heavy equipment. These estimates are shown in Table D3.

Some Cost Details

The details behind the costs shown in Table D3 were estimated with great care by the ARUV Planning Office and deserve close attention. Prices are at 1971–1972 levels. Totals apply to one building with 24 units; 12.5 buildings were to be built annually.

Table D3. ***Summary of Costs of Four-Story Industrialized Multifamily Housing Designed by the Planning Office, Puerto Rico Urban Renewal and Housing Administration***

Item	*Description*	*Cost per square foot*	*Cost per dwelling*	*Cost per building*
A	Studies, plans, and fees	$ 0.60	$ 500	$ 11,820
B	Conventional construction of foundations	0.37	300	7,200
C	Materials	2.25	1,830	44,008
D	Prefabricating plant: amortization, utilities, and so forth	0.65	530	12,700
E	Transportation of panels: amortization, fuel, and so forth	0.11	86	2,000
F	Erection of buildings: amortization, electricity, and so forth	0.23	182	4,400
G	Labor for prefabrication, transportation, and erection of panels, and general personnel expenses	1.27	1,030	24,700
H	Finishing work	4.10	3,350	80,734
I	Maintenance of dwellings during first year	0.12	100	2,400
J	Financing	0.40	320	7,700
	Net costs	$10.10	$ 8,228	$197,662
	Cost of central office and research, 15 percent	1.50	1,234	29,649
	Total costs	$11.60	$ 9,462	$227,311
	Profit and unforeseen expenses, 10 percent	1.15	946	22,731
	Selling price	$12.76	$10,408	$250,042

SOURCE: Planning Office, Puerto Rico Urban Renewal and Housing Administration, *Industrialized Housing Multistorys—Puerto Rico* (San Juan: May 1972), p. 41.

Studies, Plans, and Fees: $11,820

Royalties for the patented Estiot building system and fees to local architects and engineers amounted to $11,820. The royalty payments are charged on an area basis, estimated at $0.16 per square foot in this case, and include important consultation services. The fees are assumed to be 3 percent of what the building would have cost with conventional construction methods costing $15 per square foot.

Conventional Foundations: $7,200

Foundation construction costs will vary with the site, which in this case is assumed to be level and suitable for grade beams on concrete footings. No prefabrication is involved.

Materials: $44,008

Those materials used in the foundations (Table D3, line B) or in the finishing or subcontracting (line H) are not included. Counted are the items listed in Table D4.

Table D4. ***Materials Used in the Prototype Building***

Item	*Cost*
1. Concrete, 810 cubic yards at $23 each	$18,630
2. Fine concrete for filling joints	3,160
3. Ornamental blocks, roof fill, and other concrete products, including some labor	11,008
4. Reinforcing steel, 66,000 pounds, at 10¢ per pound (includes allowance for waste)	6,600
5. Structural steel angles, channels, double T's, and so forth 21,900 pounds at 15¢ per pound	3,285
6. Wooden sunshades with steel supports	700
7. Neoprene or similar seal	600
8. Welding rods	25
Total	$44,008

SOURCE: Adapted from Planning Office, Puerto Rico Urban Renewal and Housing Administration, *Industrialized Housing Multistorys —Puerto Rico* (San Juan: May 1972).

Prefabrication Plant: $12,700

The prefabrication plant item includes amortization, utilities, maintenance, site rent, and insurance. Total investment in the plant is

Table D5. ***The Prefabrication Plant for the Prototypes***

Item	*Cost*
1. Annual amortization at a two-year rate: roads, utility connections, crane rails, platforms, panel storage supports in the delivery yard	$ 25,000
2. Annual amortization at a two-year rate: imported metal forms for walls, slabs, stairs, parapets, and walkways	47,000
3. Annual amortization at a five-year rate: office and warehouse, power substation, two mobile aluminum-covered sheds, two ten-ton gantry cranes, concrete spreader, vibrator compactor, screeder, finisher	33,000
4. Power, fuel, and water, per year	9,000
5. Maintenance: two men and spare parts, per year	24,000
6. Site rent for 5,000 square meters	10,000
7. Insurance	8,000
Total	$156,000

SOURCE: Adapted from Planning Office, Puerto Rico Urban Renewal and Housing Administration, *Industrialized Housing Multistorys —Puerto Rico* (San Juan: May 1972).

$300,000, but the financing cost is included in line J, Table D3. The $12,700 is on a per building basis and depends on full capacity operation of the entire plant at the rate of 12.5 buildings, or 300 dwelling units, per year. The more detailed figures given in Table D5 refer to the entire plant.

For a lower or higher rate of production, one cannot simply divide this sum by a different number of buildings. Use of power and spare parts would fall with a lower number, but rent and insurance would not. The life of metal forms might be somewhat extended, but probably not that of other equipment. More skilled maintenance labor, if cheap enough, could also extend the life of the forms. For a higher volume of production, additional investment in vertical battery casting equipment and steam curing equipment could be added.

Transportation of the Panels: $2,000

If the project site is less than 16 to 24 kilometers from the plant, then 30-ton trailers could make four round trips per day, carrying four large panels on A-frames each trip. The investment in the four trailers, three tractors, and one pickup truck would be $83,000, amortized in five years. Fuel and maintenance are estimated at $8,400 for handling a 300-unit volume.

Erection of Buildings: $4,400

Erection of buildings includes amortization, installation, electricity, and maintenance. The $90,000 crane and the $15,000 of rails and ties are the fixed investment involved in this phase and should be amortized in five years. Per year their maintenance will cost $12,000, use of electricity (about 84,000 kilowatts), $5,280. For the proposed volume of four-story buildings, the crane and tracks would have to be dismantled and set up again twice a year, costing $6,000 each time. This expense, which includes much labor, is a variable cost from the enterprise's viewpoint, but a fixed cost from the point of view of the site. Uncertainties associated with all these erection operations make it wise to add 10 percent for contingencies.

Labor and Personnel Expenses: $24,700

The labor referred to in this expense category is for prefabrication, transportation, and erection of panels; also included are other general personnel expenses. To make this estimate, the Planning Office used European rates of man-hours per physical unit of output and increased them by 10–20 percent to compensate for lower Puerto Rican productivity. The result was then multiplied by an average man-hour cost. The total was raised by 20 percent to include supervisory, clerical, and other general expenses.

The average man-hour cost (in early 1972) was estimated at $2.60. This is the sum of the legal minimum wage ($1.60), an efficiency bonus ($0.20), Social Security and fringe benefits ($0.40), and an allowance for the foremen's wage differential ($0.40). Otherwise, the cost would be $2.20.

Each dwelling unit requires 330 man-hours of labor in the proportions shown in Table D6. The 330 man-hours are not the total required for the dwelling unit because every other category of expense, except materials and financing (lines C and J, Table D3), also involves working time. The quantity added by raising the 330 man-hours 20 percent for general personnel expenses is uncertain, since supervision and management are more highly paid than site and plant labor.

Finishing Work: $80,734

The finishing phase, consisting of the activities shown in Table D7, constitutes over one-third of total costs. Since these activities are to

Table D6. ***Man-Hours per Prototype Dwelling Unit Spent in Prefabrication, Transportation, and Erection***

Activity	*Man-hours*
1. Prefabrication of wall panels, 12.6 square feet per man-hour	46
2. Prefabrication of floor panels, 10 square feet per man-hour	82
3. Prefabrication of stairs and walkways	40
4. Storage of panels	12
5. Cleaning and various minor plant jobs	36
6. Transportation, assuming 10–15 mile radius, four men per trailer	32
7. Erection: one hoist operator, one welder, five helpers, 20 minutes per panel, 15 panels per house plus stairs and walkways	37
8. Completion of joints: placing formwork and reinforcing, and pouring cement, two men	16
9. Contingencies, 10 percent	29
Total	330

SOURCE: Adapted from Planning Office, Puerto Rico Urban Renewal and Housing Administration, *Industrialized Housing Multistorys — Puerto Rico* (San Juan: May 1972).

remain largely subcontracted, they are also likely to remain labor intensive. If one-third of the expenditures go for labor, the amount will somewhat exceed the labor expenses of the previous category.

Maintenance during First Year: $2,400

Until the occupants have moved in, the contractor must keep the building in working order. An expense of $100 per unit is assumed. This is the sort of item that an inexperienced planner or investor is likely to overlook.

Financing: $7,700

Assumed are a 10 percent charge for the capital of the construction enterprise and a 13 percent charge for outside capital. The entrepreneurial capital needed for a minimum volume operation is $375,000 if $450,000 can be obtained from other sources, a total of $825,000. Since 12.5 buildings are to be constructed annually and sold for $250,000 each, a total of $3,125,000, the amount of capital required by the enterprise equals about one-quarter of the value.

The fixed capital needed for plant, transportation, and erection equipment is $488,000, but this amount is rounded upward for con-

Table D7. *Finishing Costs, Including Materials and Labor, for Prototypes*

Item	*Cost*
1. Partitions (gypsumboard or asbestos-cement)	$ 8,000
2. Plumbing core walls (same material) 24 units at $86.00	2,064
3. Electrical installation	
Interior installations	10,000
Exterior installations	6,000
4. Plumbing, installation, and fixtures	20,000
5. Asphalt tile floors	4,630
6. Flush wood doors (144 units), fitting and hanging	4,300
7. Aluminum jalousie windows with subframe or buck (3,600 square feet)	5,750
8. Kitchen cabinets (24 units) and installation	4,200
9. Closet shelves and clothes poles in 72 closets	2,160
10. Interior and some exterior painting (no plastering needed)	3,600
11. Clothes lines and general cleaning up	1,960
12. Grading of yard areas for drainage, no landscaping	250
13. Miscellaneous and contingencies (24 units at $20.00)	480
Total direct cost per building	$73,394
Supervision by general contractor, 10 percent	7,340
Total cost per building	$80,734
Average cost per dwelling unit	$ 3,350
Unit cost: $4.10 per square foot	

SOURCE: Adapted from Planning Office, Puerto Rico Urban Renewal and Housing Administration, *Industrialized Housing Multistorys —Puerto Rico* (San Juan: May 1972).

tingencies to $600,000. An enterprise, according to ARUV, should be able to finance one-fourth of that out of its own funds, or $150,000.

In addition, it should have $225,000 for working capital to allow payment of the following amounts during 60 days: materials $60,000; wages $120,000; general expenses $25,000; interest, commissions, and other contingencies $20,000.

An additional amount is added for the costs of the "central office" and research. Overhead and taxes could be considered part of this item. This addition and all the contingencies allowed for throughout the budget may seem extravagant, but they correspond roughly to actual practice in the building industry. Firms that do not make these allowances tend not to survive in a highly volatile sector. Indeed, a further 10 percent is added to arrive at the selling price as "profit." If everything goes well, and this 10 percent accrues to the enterprise, the rate of return on its $375,000 investment would be 75.8 percent, in addition to the 10 percent already included under finance. One should recall, however, the two- to three-year delay from idea to first sales, the risks of excess capacity during the five-year amortization period, and the need to include the entrepreneurs' own expected income as part of the costs.

Capital-Labor Substitution through ISB

Without detailed statistics about alternative building methods for equivalent dwellings, we cannot say how much labor would have been displaced by the proposed ARUV-Estiot system. If plant and transport equipment (including contingencies and rounding) cost $470,000 and employ 30 workers, capital per worker is $15,700. Per dwelling unit, the investment is $1,600. This ratio contrasts with $51,200 per worker and $4,300 per dwelling unit in the more integrated and automated RELBEC-Larsen-Nielsen system.

But these ratios are not very helpful. Since capital includes various types of equipment that are amortized and charged for, including royalties, at different rates, a total investment cannot automatically be labelled as "too high" for given wage rates and employment. One must compare the annual rate of expenditures on one factor with another at the margin for a given output.

For the ARUV-Estiot system, the annual labor-displacing expenditure on production, transport, and erection is $250,000. This figure is based on the arbitrary assumption that capital expenditures would have been one-third as high with traditional building methods. Per building, the cost would then be $19,100, the sum of lines D, E, and F in Table D3, times two-thirds plus the cost of royalties ($3,120). The total must be multiplied by 12.5 or the annual number of buildings, which yields $198,000. Finally, $52,000 must be added as a 13 percent financial or interest charge on $400,000.

If traditional methods could produce these dwelling units at the same price but using labor instead of the prefabrication molds and cranes, one can simply divide the saved two-thirds of the annual capital cost (plus royalties) by the annual earnings per worker to estimate lost employment. The $2.60 hourly rate implies annual earnings of $5,200 per worker. Divided into $250,000, the implied lost employment is 48.1 man-years.

To the extent that the industrialized system is more efficient, even more employment would have been lost. If traditional methods had cost 10 percent more, and if all of this difference were in the form of labor, then an additional 54.6 man-years would be involved, making a total of 102.7 workers per year.

Note that, under these assumptions, the amount of capital needed to displace a worker, $4,600, is much less than the remaining capital per worker of $15,700. If costs are equal with both methods, the amount of capital implied to displace one of the 48.1 man-years is $9,800.

A full analysis would go on to consider the employment generated by supplying the capital equipment compared with that generated by the consumption of the workers, ad infinitum. Since 60 percent of capital investment goes for imported cranes, molds, trucks, and trailers, the alternative of workers' consumption probably would have created more work in Puerto Rico. In any case, the government rejected the plan as too costly and too mechanized.

Conclusion

The Puerto Rican ARUV-Estiot data are of particular significance for a number of reasons. First, the system involves a comparatively modest volume and low level of sophistication. Simple four-story buildings with six apartments per floor were to be built in pairs. Second, the data come from official government sources, not promotional sales literature, and are probably reliable. Third, Puerto Rico would seem to be especially suitable for ISB.

Not only are Puerto Rican incomes much higher than those of most developing countries, but also the relative costs of land, labor, and capital are favorable to dense, capital-intensive construction.

But if ISB cannot succeed under the favorable circumstances of Puerto Rico, where can it? Any authoritarian country can simply forbid conventional construction methods and decree that all dwellings must come from one or two component factories. Variety will be lacking, but volume will be sufficient.

Housing authorities and developers in other countries who are tempted by ISB should compare their volumes, density, capital supply, and wage rates with those of San Juan. Industrialized building systems are likely to be an investment in unemployment without compensating gains.

Notes

Introduction

1. Unless otherwise specified, assertions are based on W. Paul Strassmann, "The Construction Sector in Economic Development," *Scottish Journal of Political Economy* 17 (November 1970): 391–410. This study analyzed the period 1955–1964 for a sample of 27 countries with good data and populations over one million. The results were generally confirmed by Leland Burns and Leo Grebler, *The Housing of Nations* (London: Macmillan, 1977), pp. 20–43.
2. Thomas Edens, "Fluctuations in Foreign Exchange Reserves and in the Volume of Construction: The Similarity between Industrialized and Nonindustrialized Countries in 1870–1914 and Their Divergence in 1955–1968," Ph.D. diss., Michigan State University, 1972.
3. Hollis Chenery and Lance Taylor, "Development Patterns among Countries over Time," *Review of Economics and Statistics* 50 (November 1968): 391–416.
4. United Nations, *World Housing Survey*, E/C.6/129 (New York: September 1973), pp. 205–10.
5. Richard A. Lester, "Negotiated Wage Increases, 1951–67," *Review of Economics and Statistics* 50 (May 1968): 173–81.
6. United Nations, *World Housing Survey*.
7. United Nations, *A System of National Accounts*, Studies in Methods, Series F, no. 2, rev. 3 (New York: 1969), p. 114. The passage is condensed and clarified.
8. United Nations, *World Housing Survey*, p. 154; and Adam Adrzejewski and Mieczyslaw Kucharski, *Financing Housing in Socialist Countries* (New York: United Nations, 1968).

Chapter 2

1. United Nations, *World Housing Survey*, p. 228.
2. Göteborg Data Group, *Rapport fran Byggforskningen*, nos. 8 and 9 (Stockholm: 1969).
3. Wolfgang Triebel, "The Application of Results of Research on Rational Construction Methods and Their Practical Effect," in *Innovation in Building, Contributions at the Second CIB Congress* (New York and Amsterdam: Elsevier, 1962), pp. 154–59.
4. E.F. Schumacher, "The Work of the Intermediate Technology Development Group in Africa," in *Employment in Africa: Some Critical Issues* (Geneva: International Labour Office, 1973), p. 136.
5. Peter J. Cassimatis, *Economics of the Construction Industry*, Studies in Business Economics No. 111 (New York: National Industrial Conference Board, 1969), p. 72.

6. Gerard Boon, "Employment Creation by Technology and Output Variation in Mexico," in Christian Araud et al., *Studies on Employment in the Mexican Housing Industry*, Development Center Studies, Employment Series no. 10 (Paris: OECD, 1973), p. 179.
7. United Nations, *World Housing Survey*, p. 207.
8. James Spillane, "Interviews with Construction Firms" (Bogota, Colombia: August 1972, mimeographed), pp. 3–6.
9. A. Alweyl, "Industrialization of Building in Israel as a Rapidly Developing Country," in *Toward Industrialized Building* (New York and Amsterdam: Elsevier, 1966), pp. 441–43.
10. *Summaries of Research Projects*, no. 3 (Haifa, Israel: Building Research Station, Technion, March 1965).
11. Boon, "Employment Creation," pp. 141–52. Estimates of elasticities of substitution were not published but are available from Dr. Gerard Boon, El Colegio de Mexico, Mexico City.
12. For similar results and more details for 1955–1964, see Strassmann, "Construction Sector," pp. 401, 404 (note 1, chapter 1, above).
13. But see Paul Strassmann, "Employment and Financial Alternatives in Mexican Housing," in Araud et al., *Mexican Housing Industry*, pp. 227–303.
14. Document made available to the author by the firm.
15. This study is being made by the Instituto de Desenvolvimento da Guanabara for the Banco Nacional da Habitação. See W. Paul Strassmann, "Employment Generation through Residential Construction in Rio de Janeiro," a report sponsored by the Brazilian National Housing Bank and USAID, executed partly by the Instituto de Desenvolvimento da Guanabara during 1973 - 1975 (East Lansing: Michigan State University, October 1975).
16. A library of sources could be cited, beginning with Kenneth Arrow, Hollis Chenery, Bagicha Minhas, and Robert Solow, "Capital-Labor Substitution and Economic Efficiency," *Review of Economics and Statistics* 43 (August 1961): 225–50; Jan Kmenta, "On Estimation of the CES Production Function," *International Economic Review* 8 (June 1967): 180–89, and *Elements of Econometrics* (New York: Macmillan, 1971), pp. 463–65. For a thorough review see Jacques Gaude, "Capital Labour Substitution Possibilities: A Review of Empirical Research," WEP Working Paper (Geneva: International Labour Office, 1974), now published as chapter 2 in Bhalla, ed., *Technology and Employment in Industry* (Geneva: International Labour Office, 1975), pp. 35–58.

Chapter 3

1. Promoters of industrialized systems building (ISB), discussed in chapter 6, are among the exceptions to this generalization.
2. See chatper 7.
3. See pp. 123–24, chapter 6.
4. "Research Priorities in India," *Building Research and Practice* (May–June 1973): 133.
5. *Build International* (November-December 1971).

6. The sponsors were Wilson Chong and Associates and the West Indies Home Construction Company. See *Interbuild* (May 1965), and *Overseas Building Notes*, no. 115 (February 1967).
7. Velayudhan Raveendran and Madasamy Arockiasamy, "Construction Methods for Low Cost Housing in India," in *Proceedings of the Second International Symposium on Lower Cost Housing Problems* (Rolla: University of Missouri, 1972), pp. 271–72.
8. *Build International* (April 1970).
9. *Indian Concrete Journal* (March 1964).
10. *Prefabrication* (December 1958).
11. Building Research Station, Waterford, England, *Overseas Building Notes*, no. 150 (June 1973): 8. Just as wood has a tendency to become food for termites, air spaces in walls tend to become breeding areas for insects and vermin.
12. Department of Housing and Urban Development, *Results of Experiments on Stabilizing Soil that Is to Be Used as a Building Material in Iran*, Ideas and Methods Exchange no. 51 (Washington, D.C.: 1958). Ideas and Methods Exchange no. 22, *Earth for Homes*, was issued in 1955. The Agency for International Development has also issued an undated *Handbook for Building Homes of Earth.*
13. *Prefabrication* (November 1953).
14. *Colonial Geology and Mineral Resources*, vol. 4, no. 4 (1954).
15. *Indian Builder*, annual issue, 1967.
16. *Journal of the National Building Organization* (October 1965).
17. I.S. Uppal, "Low-Cost Durable Shelters," *Build International* (March–April 1972).
18. Chief of the program in 1973 was Ing. José Meza Cuadra, Office of Construcción con Bloque Estabilizado, Ministerio de Vivienda, Lima, Peru.
19. *Journal of the National Building Organization* (October 1961) and (October 1965).
20. Agency for International Development, *Front Lines*, 15 September 1977, p. 6.
21. *Modular Quarterly* (Winter 1963–1964); and Ashfaq Hasan and Mian M. Hanif, *Review of Building Research Activities in West Pakistan* (Lahore: Building Research Station, 1970), pp. 1–3.
22. Department of Housing and Urban Development, *Plant Requirements for Manufacture of Building Bricks* (Washington, D.C.: 1955, reprinted 1967). This example assumes that all factors are available at U.S. prices and levels of quality; no factor substitutions whatsoever are allowed. The assumption of a forty-hour work week for the plant precludes greater labor intensity.
23. Marion Bowley, *Innovations in Building Materials: An Economic Study* (London: Duckworth, 1960), pp. 81–82.
24. Pedro de Cespedes, *El Mercado de Tabiques en el Distrito Federal* (Mexico City: 1964).
25. W. Paul Strassmann, "Innovation and Employment in Building: The Experience of Peru," *Oxford Economic Papers* (July 1970): 248–49.
26. *Prefabrication* (March 1958).

27. Hasan and Hanif, *West Pakistan,* p. 3. For a detailed empirical study of comparative quality, labor intensity, capital costs, and economies of scale in making concrete blocks in various ways, see Frances Stewart, "Manufacture of Cement Blocks in Kenya," chapter 8 in Bhalla, ed., *Technology.*
28. Southwest Research Institute, *Technique for Sulfur Surface Bonding for Low-Cost Housing* (San Antonio, Texas: 1975), cited in Albert Dietz and Fred Moavenzadeh, "Innovative Uses of Materials for Housing in Developing Areas," *International Journal for Housing Science* 1 (October 1977): 140–41.
29. Marion Bowley, *The British Building Industry: Four Studies in Response and Resistance to Change* (Cambridge: the University Press, 1966), pp. 15–19.
30. *British Construction Engineer* (June 1957).
31. *Engineering News Record,* 3 February 1972.
32. *Proceedings of the International Symposium on Low Cost Housing Problems Related to Urban Renewal and Development* (St. Louis: University of Missouri, October 1970).
33. National Academy of Sciences, *Ferrocement: Applications in Developing Countries* (Washington, D.C.: February 1973).
34. Otto Koenigsberger and Robert Lynn, *Roofs in the Warm and Humid Tropics* (London: Land Humphries for the Architectural Association, 1965), p. 12.
35. Ibid., pp. 42–47.
36. *Indian Concrete Journal* (June 1956) and (March 1960); and *Indian Builder,* annual issue, 1967.
37. A. el-Arousy, "Types of Building Industrialisation Fit for Developing Countries," in *Toward Industrialized Building, Proceedings of the Third CIB Congress* (Amsterdam: Elsevier, 1966), pp. 444–46.
38. The 1968 Peruvian sample is described in Strassmann, "Peru," pp. 243–59.
39. Hasan and Hanif, *West Pakistan,* p. 4.
40. *Prefabrication* (January 1955). Prices in 1972 would be about 77 percent higher.
41. *Build International* (January-February 1970).
42. *Ceres,* FAO Review (July-August 1972): 58; and *Interbuild* (March 1966): 28.
43. S.C. Paraskevopoulos, "Foam Plastics for Housing in the Interest of International Development," in *Toward Industrialized Building* (Amsterdam: Elsevier, 1966), pp. 342–44.
44. R.E. Platts, *The Role of Plastics in House Structure* (Ottawa: Division of Building Research, 1964), p. 16.
45. "Plastics for Building in Developing Countries," *Overseas Building Notes,* no. 134 (September 1970): 6, 8.
46. "Durability of Materials for Tropical Building," *Overseas Building Notes* (August 1972); and "Report Warns of Flammability of Plastic Building Materials," *Engineering News Record,* 26 October 1972, p. 16.
47. *Engineering News Record,* 7 June 1973, p. 10.
48. Center for Development Technology, *Summary Report* (St. Louis: Washington University, 1972), pp. 10–12.

Chapter 4

1. W. Paul Strassmann, *Technological Change and Economic Development: The Manufacturing Experience of Mexico and Puerto Rico* (Ithaca: Cornell University Press, 1968), pp. 185, 228.
2. CBRI, *Annual Report 1968;* and *Build International* (July–August 1970).
3. Strassmann, "Peru," pp. 246, 252.
4. Ibid., p. 250.
5. Charles Abrams, *Housing in the Modern World* (London: Faber and Faber, 1964), p. 179.
6. Such a house has often been discussed, but in November 1973 architects at Cambridge University, England, announced that they would actually build one with a £31,000 grant from the Science Research Council and the Department of the Environment. Since human faeces were not expected to yield enough energy, the group planned supplements with windmills and perhaps small herds of goats. *Sunday Times,* 25 November 1973, p. 3; and Paris *Herald Tribune,* 24–25 November 1973, p. 2.
7. Philip Arctander et al., "Scandinavian Idea Competition: Housing in Developing Countries," *Ekistics* (May 1971): 334–40.
8. D.J. Dwyer, *People and Housing in Third World Cities* (London: Longmans, 1975), pp. 232–36, based partly on Uno Winblad, *Evaluation of Waste Disposal Systems for Urban Areas* (London: Consulting Group for Planning, Architecture and Building, 1972).
9. D.N.W. Chinnery, "Performance Tests on Solar Water Heaters," *Overseas Building Notes,* no. 103 (September 1965); and *Build International* (March–April 1971).
10. el-Arousy, "Types of Industrialisation," pp. 444–46.
11. *Journal of the National Building Organization* (October 1969).
12. *Innovation in Building,* pp. 108–15.
13. *Journal of the National Building Organization* (October 1965); and *Build International* (April 1970).
14. *Royal Engineers Journal* (June 1960). For conventional ways of prolonging the life of wood houses, see Department of Housing and Urban Development, *Prolonging Life of Wood Houses,* Ideas and Methods Exchange no. 47 (Washington, D.C.: 1957).
15. W.S. Forbes and Rosemary Stjernstedt, "The Finchampstead Project," *Building,* 13 October 1972, pp. 111–24.
16. See United Nations, *The Use of Bamboo and Reeds in Building Construction,* ST/SOA/113 (New York: 1973).
17. A.J. Stevens, "Activity Sampling on Building Sites," *Work Study* (February 1969): 27–33.
18. W.S. Forbes and J.F. Mayer, "The Output of Bricklayers," *Building,* 26 January 1968, p. 146.
19. *Build International* (March–April 1971).
20. Central Building Research Institute, *Annual Report* (Roorkee, India: 1970), pp. 33–34; and *Build International* (July–August 1970): 218.
21. HUD International, *Information Series,* no. 2, 31 May 1970.
22. R. Spence, "Low-Cost Building in Kerala," *Appropriate Technology,* vol. 1, p. 12.

23. Triebel, "Rational Construction Methods and Their Practical Effect," in *Innovation in Building*, p. 154.
24. Forbes and Stjernstedt, "Finchampstead Project."
25. Ibid.
26. Raveendran and Arockiasamy, "Low Cost Housing in India," pp. 271 – 74.

Chapter 5

1. Maurice G. Kendall and Alan Stuart, *The Advanced Theory of Statistics*, 2d ed. (New York: Hafner Publishing Co., 1967), vol. 2, pp. 540 – 61.
2. A.D. Daldy and R. Sperling, "Setting Up a National Building Research Station," *Build International* 3 (July – August 1970): 211 – 14.

Chapter 6

1. P.A. Stone, *Urban Development in Britain: Standards, Costs, and Resources: 1964–2004* (Cambridge: the University Press, 1970), p. 228.
2. See Table D3.
3. See Table C3.
4. United Nations Economic Commission for Europe, various reports on housing costs.
5. See Table C5.
6. See Table 18 below.
7. C.B. Patel, cited in Committee on Housing, Building and Planning, United Nations Economic and Social Council, *Housing Policy Guidelines for Developing Countries*, E/C.6/VIII/B.P.3 (New York: August 1973), p. 121. See also K.L. Datta, "Intensive Use of Land for Economy in Housing Developments for Lowest Income Groups," *SMUH Bulletin Trimestrial* (Paris) (July 1971): 17 – 28.
8. Calculated from Table C5.
9. Stone, *Urban Development*, pp. 293 – 97.
10. Carl W. Condit, "Building and Construction," in Melvin Kranzberg and Carroll Pursell, eds., *Technology in Western Civilization* (New York: Oxford University Press, 1967), vol. 1, pp. 367 – 92, 602 – 19.
11. Humphrey Chamberlain, "The Manufacture of Bricks by Machinery," *Journal of the Royal Society of Arts* (6 June 1856).
12. Bowley, *British Building Industry*; and D. Knoop and G.P. Jones, "Rise of the Mason Contractor," *Journal of the Royal Institute of British Architects* (1935 – 1936): 1061 – 71.
13. Catherine Bauer, *Modern Housing* (Boston: Houghton Mifflin, 1937), p. 207; and Bowley, *British Building Industry*, pp. 61 – 64.
14. Ian Donald Terner and John F.C. Turner, *Industrialized Housing* (Washington, D.C.: U.S. Agency for International Development, 1972), p. II-4, and sources cited there.
15. Committee on Industrialized Housing, National Academy of Engineering, *Industrialized Housing* (Washington, D.C.: 1972).
16. "Corporate Thoughts from a Successful Alumnus," *Transacta* 6, no. 1, 1973, pp. 11 – 12.

17. Peter C. Williamson, "Tomorrow's Housing," *Engineering News-Record*, 30 April 1974, p. 139. The person quoted is Vance Torbert. Major participants in the program such as Levitt and Sons, National Homes Corporation, Boise-Cascade Corporation, and Rouse-Wates, Inc., had all ceased making their panels and modular boxes by April 1974. The General Electric Company Re-Entry and Environmental Systems Division had halted production, pending the development of a cementitious instead of a steel-plaster wall system. Lack of subsidies and markets was mentioned as the principal difficulty. Occupants of finished breakthrough housing had the same general complaints about fixtures, plumbing, doors, windows, and so forth, as occupants of regular housing. Continuing in operation were two Cleveland producers, Forest City Enterprises and its wholly owned subsidiary, Thomas J. Dillon and Company. These used concrete and wood panels and bathroom modules. The U.S. General Accounting Office evaluated the program to determine if the innovations generated were worth the $137 million expended. *Engineering News-Record*, 4 April 1974, p. 9. A caption to the article read: "Factory-made boxes made economic sense on paper, but . . . ."
18. A good theoretical discussion is that by Richard F. Muth, *Cities and Housing: The Spatial Pattern of Urban Residential Land Use* (Chicago: University of Chicago Press, 1969).
19. National Housing Board, "Sweden: Current Trends and Policies in the Fields of Housing, Building and Planning" (Stockholm: 1973, mimeographed), Part I, pp. 2–3; Part II, pp. 6–7.
20. Ministry of Housing, "Denmark: Current Trends and Policies in the Field of Housing, Building and Planning, 1972–73" (Copenhagen: 1973), pp. 1–3, 20.
21. Ministère de l'Aménagement du Territoire, de l'Equipement, du Logement et du Tourisme, *Tendances et politique actuelles dans le domaine de l'habitation, de la construction et de la planification* (Paris: July 1973), pp. 1–3, 18–25, and other information obtained directly from the ministry.
22. Ministry of Housing and Physical Planning, "The Netherlands: Current Trends and Policies in Housing and Building in 1971–72" and "Supplement 1973" (The Hague: 1972), pp. 24–25, 50–51, 64–65.
23. As is often the case with aggregate data, these apparent trends are partly changes in composition. The most efficient systems survived, and efficiency of any given system changed less. The data also hide regional variations. The typical pattern of a decline from a 41 percent to an 18 percent share in terms of dwelling starts was that of London and the southeastern counties (1968–1972). But in the northwest the share fell less, from 48.7 to 33.8 percent, while in East Anglia it even rose from a low of 7.4 to 8.7 percent. In the north and southwest, it fell drastically, from 31 percent to 3.5 percent.
24. Department of the Environment, "United Kingdom Country Memorandum" (London: 1973, mimeographed), p. 12. In part because of the low cost of British bricks and, consequently, brick housing, in comparison with reinforced concrete apartments, British densities had always remained lower than those of the Continent. The Continent also had lower incomes

in general before about 1960, more destruction during the war, and less of a sustained building program during the 1930s. As a partial reaction to the drawbacks of systems building, some new towns such as Thames-Meade have been largely avoiding it. See also Stone, *Urban Development*, pp. 222–32.
25. Building Research Establishment, *Information* (September 1972): 1. See also *Build International* (September–October 1972): 261–62.
26. Housing and Development Board, *Annual Report* (Singapore: 1973), pp. 9–37.
27. S. Peer, "Economics of the Prefabrication of Single Elements in Conventional House Construction," in *Toward Industrialized Building*, pp. 297–99.
28. United Nations Technical Assistance Program, *Housing in Ghana*, ST/TAA/K/GHANA/1 (New York: September 1957), pp. 127–35.
29. *Overseas Building Notes*, no. 70 (October 1960); and *Prefabrication* (November 1955).
30. See also chapter 3; and Strassmann, "Peru," pp. 243–59.
31. International Labour Office, *Sharing in Development: A Programme of Employment, Equity and Growth for the Philippines* (Geneva: 1973), chapter 7.
32. Department of Economic and Social Affairs, United Nations, *Pilot Housing Project in Central America*, ST/ECA/172, p. 106.
33. *Chien-chu hsueh-pao* (Journal of architecture) 1963, no. 10, p. 22, cited in Kang Chao, *The Construction Industry in Communist China* (Chicago: Aldine, 1968), p. 181.
34. Ibid., p. 152.
35. Armour Research Foundation, *Estudio Tecnológico de Varias industrias Mexicanas, con Recomendaciones sobre la Investigación Industrial, Problemas Agricolas e Industriales de Mexico*, vol. 1 (Mexico City: 1945).
36. Instituto Nacional de Vivienda, *La Vivienda de Interés Social* (Mexico City: 1967).
37. Secretaría de Hacienda y Crédito Público and Fondo de Operación y Descuento Bancario a la Vivienda, *Programa Financiero de Vivienda: Evaluación y Proyección* (Mexico City: 1970), pp. 130–31.
38. Mahesh Bhatt, "Housing Problem of a Growing Metropolis," *Economic and Political Weekly*, 22 April 1972, pp. 849–51; and D.R. Gadgil, *Planning and Economic Policy in India* (Poona: Gokhale Institute of Politics and Economics, 1972), pp. 16, 172–79, 186.
39. Central Building Research Institute, *Annual Report* (Roorkee, India: 1962 through 1970).
40. Zenon A. Zielinski. "Role of Prefabrication in Low-Cost Housing," *Papers on Housing* (Calcutta: Metropolitan Planning Organisation, 1969), p. 29.
41. I.S. Uppal, "Low-Cost Durable Shelters," *Build International* (March–April 1972): 100–101.
42. *Seminar*, February 1973, p. 11.
43. Ibid., pp. 14, 22, 24.
44. Ibid., p. 19. For an example, see the designs of I.S. Baker described in Spence, "Kerala," p. 10.
45. *Seminar*, February 1973, p. 38.
46. "Probing the Future," *Engineering News-Record*, 30 April 1974, pp. 68–69.

Chapter 7

1. This chapter was presented as a discussion paper to the United Nations Ad-Hoc Expert Group at its meeting on Criteria for the Selection of Appropriate Building Technologies, Amman, Jordan, 12–17 December 1977.
2. Two decades ago, I surveyed the literature in "Economic Growth and Income Distribution," *Quarterly Journal of Economics* 70 (August 1956): 425–40.
3. Frances Stewart, "Technology and Employment in LDC's," *World Development* (March 1974): 23. Stewart also notes that "an example of excess standards is of a brick strong enough to support a four-storey building, used for a single-storey house" (p. 22). Such high standards, as in the case of concrete blocks, involve more capital-intensive production and transport methods (p. 26). Her overall conclusion appears unduly pessimistic, however, since "reforms, which virtually amount to revolutions, are needed" to get appropriate factor prices, income distribution, and technology (p. 35). In a later article, Stewart and Paul Streeten add that workers in modern factories "must be fed, housed, educated more or less to Western standards," meaning that "private and public expenditure must be disproportionately concentrated . . . . Strategies towards poverty alleviation are easy to devise so long as the critical links between technology and income distribution, income distribution and decision makers, and decision makers and objectives, are ignored."
4. E. Abebe, "Background and Discussion Paper," p. 183, United Nations Ad-Hoc Expert Group Meeting on Criteria for the Selection of Appropriate Building Technologies, Amman, Jordan, 12–17 December 1977.
5. Ibid., p. 208.
6. Michael Cohen, *Urban Policy and Political Conflict in Africa: A Study of the Ivory Coast* (Chicago: University of Chicago Press, 1974), pp. 33–35.
7. Ibid., pp. 129, 153–55.
8. Implied is a semilogarithmic social utility function. Equal weight can be given to equal percentage improvements in housing conditions for any household. The rise in housing welfare is therefore not just a function of the volume of construction and the flow of housing services from the dwelling stock. Welfare also depends on *how* this flow is distributed. For a mathematical derivation, see W. Paul Strassmann, "Housing Priorities in Developing Countries: A Planning Model," *Land Economics* 53 (August 1977): 310–27.
9. Ibid. To bring the index to 100 would take 6 percent of GCP, or an extra $196 million.
10. If the investment constraint rises to 6 percent of gross city product, 35,000 more H_4 dwellings should be built and 36,000 fewer H_3 dwellings. One can even allow 1,000 luxury houses. On the other hand, if the constraint falls to 3 percent, then the volume of H_3 construction should fall by 53,000 because that many more H_2 dwellings must be built. The author has applied the model to Sri Lanka and Puerto Rico. An application to Tunisia is found in Ridha Ferchiou, "New Construction, Subsidies, and Filtering of Dwellings in Tunisia: A Vacancy Chain and Linear Programming

Analysis," Ph.D. diss., Michigan State University, 1975. An application to Mexico is found in Jesus Yáñez Orviz, "Optimal Allocation of Housing Investment in Five Mexican Cities, 1960–70, 1970–85," Ph.D. diss., Michigan State University, 1976. Both Ferchiou and Yáñez contributed important ideas toward making the theory workable.

Appendix A

1. Araud et al., *Mexican Housing Industry*, especially pp. 80, 163. It was assumed that offsite construction labor is paid at double the rate as onsite labor. Other figures are empirical.
2. See Strassmann, "Alternatives in Mexican Housing," pp. 227–303; and W. Paul Strassmann, "Empleo en la Construcción, Valor de la Tierra y Financiamiento," *Demografía y Economía* 7 (1973): 338–49.

Appendix B

1. Jesús Osuna collected the data and made all calculations in this appendix, as well as contributed a number of ingenious suggestions. The author is greatly indebted to him.
2. Cassimatis, *Construction Industry*, pp. 73, 99.
3. Kmenta, *Econometrics*, p. 463.
4. If common logarithms are used instead of natural ones, β_4, and hence ρ itself, has to be multiplied by 2.302585.

Appendix C

1. Strassmann, "Construction Sector," pp. 391–409. Only housing in the monetized sector is included.
2. Departamento Nacional de Planeación, *Posibilidades de Reducción de Costos en Edificación* (Bogota: November 1972), p. 2.
3. International Labour Office, *Towards Full Employment* (Geneva: 1970), p. 128.
4. "La Construcción en Colombia, 1948–1972," *Bolentín Mensual de Estadística* (May–June 1973): 82, 91–93.
5. Ibid., pp. 207–43.
6. ILO, *Towards Full Employment*, p. 132.
7. Ibid., pp. 133–34, 398–99.
8. United Nations, *Report of the Seminar on Prefabrication of Houses for Latin America*, ST/TAO/SER.C/141 (New York: 1972).
9. Details of this experience in Colombia are given in chapter 3.
10. Santiago Luque Torres, "Classificación de los Sistemas de Prefabricación en Colombia," in *Memorias del Primer Seminario Latinoamericano sobre Prefabricación Aplicade a la Construcción de Viviendas de Interes Social* (Bogota: Instituto Colombiano de Normas Téchnicas, 1972), pp. 20–22.
11. Lucia Raffo de Mascaro, "La Prefabricación en la Producción de Viviendas Economicas — Analisis de la Situación Argentina: Propuesta de Política a Seguir," in ibid., p. 11.
12. *Memorias del Primer Seminario Latinoamericano*, pp. 37–38.

13. Cited in note 2 above.
14. Departamento Nacional de Planeación, *Posibilidades,* pp. 23, 28.
15. Ibid., pp. 48–53.
16. Ibid., pp. 63–68.
17. Ibid., pp. 69–76.
18. Ibid., pp. 88, 101, 104.
19. The preceding three paragraphs are based on *Posibilidades,* pp. 194–96 and Chart 6.1.
20. *Posibilidades,* Table 6.10 and Appendix 2.
21. Ibid., p. 212.
22. ILO, *Towards Full Employment,* pp. 377, 171, 134–35.
23. Ibid., pp. 181–82, 171–72.
24. Ibid., p. 135.
25. A pioneering analysis of housing in Colombia is Lauchlin Currie, *Una Politica Urban para los Paises en Desarrollo* (Bogota: Tercer Mundo, 1965).

Appendix D

1. Puerto Rican Urban Renewal and Housing Administration, Planning Office, *Industrialized Housing Systems for Puerto Rico* (San Juan: April 1971), p. 12; and Junta de Planificación, *Estudio para el Diseño de una Nueva Politica de Vivienda para Puerto Rico* (San Juan: June 1971), pp. 2, 3.
2. Committee on Housing, Building and Planning, United Nations Economic Commission for Europe, *Statistical Background Paper,* HBP/R.5 (Geneva: July 1973), pp. 3, 5.
3. For a good summary of all this, see Uriel Manheim, *Puerto Rico Builds: The Island's Housing Market in the 1970s,* 3d ed. (San Juan: Housing Investment Corporation, 1972).
4. Ibid., p. 44.
5. Junta de Planificación, *Nueva Politica de Vivienda para Puerto Rico,* p. 32.
6. Ibid., pp. 8–9, 39, 40.
7. Ibid., pp. 24, 42. Private sector economists claimed that costs had and would continue to rise less than family incomes. See Manheim, *Puerto Rico Builds,* p. 66.
8. Manheim, *Puerto Rico Builds,* p. 32. About two-fifths of these are mainland firms operating in Puerto Rico or, equally important, Puerto Rican firms building on the mainland.
9. Federal Housing Administration, *Characteristics of Operation under Section 203,* cited in Manheim, *Puerto Rico Builds,* p. 31.
10. Puerto Rican Urban Renewal and Housing Administration, Planning Office, *Industrialized Housing: Multistoreys — Puerto Rico* (San Juan: May 1972), p. 33.
11. Manheim, *Puerto Rico Builds,* p. 20.
12. RELBEC, *The Answer to Your Questions about Industrialized Housing* (Hato Rey, Puerto Rico: undated), p. 11.
13. Planning Office, *Industrialized Housing Systems for Puerto Rico,* p. 64.
14. Planning Office, *Multistoreys — Puerto Rico,* p. 8.
15. Ibid., p. 21.