

A FRAMEWORK FOR AN INITIAL DEVELOPMENT COST MODEL  
FOR SINGLE-FAMILY DWELLINGS

by

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Submitted in partial fulfillment  
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The demand for low-income, government subsidized housing has been increasing over the past several years due to the rising cost of housing. Low-income, and even moderate-income, families are finding it more and more difficult to find housing which they can afford. It is hoped that with the help of technological innovations in methods and materials of housing construction, federal subsidies, and private enterprise that the goal of decent housing can be attained for all by 1978.

The activities of these three groups, namely, the building industry, federal government, and private investors, must be coordinated if they are to interact effectively. This calls for a cost analysis of low-income housing which can be done by a total cost model consisting of submodels of total initial development, operating, and user costs.

The first step in the development of such a model is the formulation of the initial development cost submodel. The framework of such a model for conventionally built, single-family housing is the immediate goal of this research.

First, a literature review was done on the technological, social, and economic aspects of housing along with a consideration of housing models in existence now. An intensive analysis of house-building techniques and materials was carried out as well. Finally, the design and proposed operation of the initial development cost model were developed.

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## Chapter I

## SURVEY OF RESIDENTIAL BUILDING IN THE U.S.

A. Current Problems in the Area of Housing

In recent years the cost of housing has been steadily spiraling upward, and as a result, low-income families are finding it increasingly difficult to find housing which they can afford. Consequently, the demand for privately managed, federally subsidized housing has also been rising. In fact, if construction and land costs continue to climb as they have been, it may not be long before even middle-income families will need subsidized housing.

The President's Committee on Urban Housing (27) in 1968 estimated that 7.8 million American families, about one in every eight, could not afford to pay the market price for standard housing. The Housing and Urban Development Act of 1968 set a goal of 26 million dwellings, including 6 million subsidized units, to be built or rehabilitated by 1978. The President's Committee stated that attainment of this goal should eliminate the blight of substandard housing from the nation's cities and provide every American family with a decent home which it can afford. However, technological innovations in housing production, by themselves, will be unable to bring decent housing within economic reach of low-income families in the near future. Federal subsidies are necessary and must be significantly increased in order to fill the gap which will remain between the market costs of standard housing and the price that low-income families

can afford to pay. Further, the President's Committee concluded that these goals can only be attained with the help of private enterprise in the development, sponsorship, and management of such government subsidized housing.

This goal, the production of 2.6 million units annually, calls for much more massive, even industrialized, production of housing, eliminating the contact that used to exist between the individual and the contractor. Instead, there will be contact among the private investors, the government, and the building industry on a large scale. The building industry will be in need of an efficient method of evaluating the alternatives available in materials and design of construction. The government will likely be concerned with the trade-offs between initial development cost and operating or user cost. The private investor will likely be interested in a breakdown on where the money goes in initial development and operating costs and in an evaluation of a project's economic potential. Finally, the user will probably want to know what his expenses will be and whether or not the environment will suit his needs. This last set of variables is a rather subjective one, but perhaps it will be possible to attach some quantitative parameters to it. It seems, that a total cost model, including initial development, operating, and user cost models, should be useful in beginning to satisfy any or all of these potential needs which are sure to arise because of the mass construction necessary to satisfy the demand for low-income housing.

## B. Technology of Housing

Dietz (7) observes, in a paper on building technology, that in discussions about the large volume of residential building projected for the rest of this century, it is often said that the necessary technology exists and that no great improvements are either necessary or probable, but that other factors stand in the path of its full application. Furthermore, it is also said that costs of housing for low- and middle-income families are too high, but that technology cannot substantially reduce them without much financial help, such as subsidizing. Dietz (7) feels there is a contradiction here and writes the following:

If costs are too high and technology cannot substantially reduce them, then technology is inadequate. It may be true that no great improvements are possible; it may also be true that we need only to utilize fully our existing technology.

The way in which to begin to try to resolve this contradiction is to look at the existing and potential technologies and their interactions with probable constraints of social, economic, and political natures.

### B.1. Conventional Construction

Conventional construction is characterized by the fabrication of components in-place in the building, be it a house or high-rise apartment building. In comparison with prefabricated housing, conventional construction has fewer jointing problems, a smaller required project size necessary to amortize special equipment as well as less special equipment, few restrictions imposed by transportation, and no need

for space on-site for fabrication facilities. However, the high cost of the necessarily skilled, on-site labor and problems with inclement weather often prevent significant savings from being gained (18).

Timber frame construction, which is most commonly used for single-family dwellings and smaller multi-family ones, has been developed through innovations over the past two hundred years. The large number of improvements, such as insulation, heating, electricity, running water, and sewer connections, that expanding technology has made possible, have added considerably to the cost of house construction because of the added cost of the materials themselves and because of the added skilled labor required to install them (2).

Some people still feel that the large-scale home building industry has the capacity, even now, to provide housing at low costs. The mass-production of "tract builders" results in some cost reduction because of lower prices due to mass-purchasing, better bids from subcontractors who are assured of steady employment, and better scheduling which reduces idle time for labor. Furthermore, in order to counter-balance the spiraling costs of labor, conventional construction has been and will probably continue to rely more and more on the use of prefabricated parts in housing. As of now, most conventional builders rely on doors, windows, hardware, appliances, cabinets, and a variety of flooring, roofing, ceiling, and partitioning materials produced by specialized firms and installed on the job (2). The possibility of combining new materials (e.g. plastics and polyurethane

foam) and mechanical subsystems produced in a shop and installed as a unit (e.g. bathrooms and kitchens) with conventional construction seems possibly to be an optimal solution in the near future. Such a combination of technologies would hopefully result in an increased capacity to produce housing and in a reduction of construction and maintenance costs. Innovations, such as these, in materials and mechanical subsystems will be discussed in more detail later.

#### B.2. Prefabricated Construction

Prefabricated construction involves the fabrication of building components either off-site in a factory or on-site away from the final position of the components in the building. The major cost saving factors of factory fabrication are as follows: (1) improved materials handling (e.g. quantity purchases and reduced waste and/or vandalism), (2) cheaper labor (i.e. reduction in hours needed due to efficiency, no problems with weather, etc. and substitution of industrial labor for craft labor), and (3) improved management, control, and scheduling and overhead reduction. In turn, of course, these economies are reduced by the cost of transportation, need for special mechanical equipment for on-site assembly, capital recovery on plant investment, and high initial research, development, and design costs. While some prefabricators produce homes essentially by traditional craft methods in a factory setting, others replace at least some of the hand labor by machines and thus avoid some of the high labor costs (13,18). One last problem with prefabrication is that while it reduces field fabri-

cation, it imposes rigid job control in that the units must arrive and be installed in the proper sequence without preliminary storage (6).

There is no shortage of prefabrication schemes. In many respects they are more widely used and thus more advanced abroad than in the U.S., but the U.S. is catching up. Some schemes are based almost entirely on traditional technologies adapted to shop fabrication while some employ moderately advanced ideas and still others exotic ones. The various degrees of prefabrication are often classified into three groups: boxes, large panels, and pieces.

About forty companies in this country were experimenting in the box-system of construction in 1969. This is about fifty percent of all such American companies experimenting in prefabrication technologies. Most of the box-systems are still in the conceptual stage of development (18). Boxes may be room-sized or larger enclosures which may make up the entire building, such as trailers and mobile homes, or may be assembled into larger structures, such as apartment buildings. They range from comprising only the structural shell to being the final, completely furnished product with all utilities, carpets, furniture, and pictures installed. The boxes may be heavy or light depending upon the materials used which may be metal (steel or aluminum), concrete, wood, and even some of the new plastics. Some of the boxes (e.g. metal) unfold from a compact arrangement, which conforms to highway transport restrictions, to full-sized units. Big boxes are attractive because of the large amount of work done in the

factory, including prefurnishing and incorporation of utilities, but still have many problems that must be solved (7,18).

About thirty-five percent of the building systems being developed in this country fall into the category of big panels. This system has been widely used in Europe (18). Big panels are wall-sized slabs and large floor/ceiling units which are assembled at the site. A single panel may form part of several rooms and may or may not be load-bearing. Panels may be finished on one or both sides and may or may not incorporate parts of mechanical subsystems. Panels range from light to heavy depending upon materials and method of fabrication. Concrete is the most commonly used material, but wood, gypsum, metal, brick, stone, and plastics may also be used (7,18).

The most obvious advantage of big panels over boxes is that boxes are bulky whereas panels can be stacked for transport. Furthermore, boxes are more difficult to put in place. Panels result in an increase in planning and design flexibility over boxes, but at the same time they require many more joints to be made in the field and seldom permit the degree of prefinishing and shop incorporation of utilities and equipment that is possible with boxes.

Pieces consist of smaller units than big panels, namely, columns, beams, and floor slabs, assembled at the site to provide a basic structure into which are inserted in-filling non-load-bearing panels or field-fabricated parts, such as partitions. Such structural frame systems are usually fabricated in two basic materials: reinforced concrete (e.g. floor slabs) and steel (e.g. beams and columns) (7,18).

It is here that the line between prefabricated and conventional construction becomes hazy. Use of pieces allows greater flexibility in arrangement with a smaller number of different units than might be possible with big panels, simpler fabrication equipment in the factory, simpler and lighter erection equipment, and possibly pieces small enough to be handled by men alone. Of course, more joints are required and the amount of field finishing and incorporation of utilities is generally greater than with boxes and panels.

The methods of prefabrication discussed above involve off-site factory fabrication. Another method is on-site prefabrication where components are fabricated on the building site but away from their final positions in the building. All three systems described above can be prefabricated on-site. Compared with other methods of prefabrication, on-site prefabrication generally requires less initial volume of construction to amortize factory costs because of the simpler and less expensive equipment used. Of course, such a technique requires extra space to be available on the site for fabrication facilities, and this is not always possible (18).

None of these approaches are mutually exclusive nor do they eliminate mixtures of prefabricated and conventional technologies. In fact, most of the new technologies use at least some conventional procedures. Box construction often uses some panel and pieces while panel often employs some pieces as well. Foundations are nearly always fabricated in-place, and it is often more economical to cast floors in-place as well as the walls of the first floor (7). One of

the major problems in trying to combine these various technologies is the development of a basic module which is a necessity if diverse components manufactured by different industries are to fit together. Most people do agree that some kind of modular coordination is needed if construction and building design are to be simplified, but as yet, no one standard module has been generally adopted (6).

### B.3. Mechanical Subsystems

Mechanical subsystems (i.e. plumbing, heating and ventilating, and electricity) are also subject to possible improvements. Work is being done in improving the functioning of each of the various types of systems as well as developing new ones. Innovations in the installation of mechanical subsystems plays an important part in reducing construction time and money and will be discussed here.

Bathrooms, kitchens, and utility rooms represent thirty to thirty-five percent of the total cost of in-place housing (exclusive of land) (18). A mechanical system includes dozens of items traditionally manufactured separately, making several levels of innovation possible based on the extent of preassembly.

Conventionally constructed mechanical systems and their structural frameworks come to the site as separate pieces which are then assembled piece by piece. Technological innovation at this level consists of mass production of standardized pieces and efficient on-site assembly. This system, however, leaves room for lost time on the site and requires a great amount of field supervision to coordinate all activities so that they occur at their designated times.

An extension of this level is to highly engineered conventional construction in which groups of materials are preassembled by trade categories in factories, shops, or on-site and then erected as a unit (2, 18).

A step above this is the utilization of a factory-assembled service wall which contains plumbing trees, vents, flues, and electrical services to which fixtures and other appliances are connected in the field. This system could also be used with a factory-assembled floor panel in conjunction with the wall panel. This method has nearly as much flexibility as conventional construction, but it is faster and more economical. Compared with the core system discussed next, the service wall method requires less elaborate equipment on-site and in the factory and transportation costs are lower, but it requires more on-site labor and construction time (2,18).

The core concept involves a single unit which contains all utility functions and structures and is preassembled at a factory, transported to the site, and placed in the dwelling at the appropriate time. The core may be single or multiple story and may be self-supporting or capable of supporting loads external to the core itself (e.g. floors and roofs). One service connection to each of the services (i.e. electrical, water, sewage, and gas) is necessary along with some additional room wiring. Use of a service core seriously limits layout variations since kitchen and bath must be adjacent. Furthermore, special on-site handling equipment is required to move the structures. Of course, a savings is gained in reduction of on-

site labor and construction time (2,18).

Split cores have also been considered in order to eliminate the constraints on layout. This concept divides the single core into separate functional units, such as separate kitchen, bath, and utility cores, or some combination of these units. Compared with the single core, the split core increases design flexibility, but at the same time it increases on-site labor and construction time as well as materials costs. As shown above, each level of innovation has its advantages and disadvantages, both of which must be considered in order to select the appropriate approach for a particular situation (2,18).

#### B.4. Materials

Over the years, materials have also advanced considerably, and still today new materials are constantly being developed. A few of them will be briefly mentioned here. Expansive and controlled-set cements are both recent additions which should help to overcome some problems with concrete, a very major building material. New and stronger steels, high-stress bolts, and sprayed-on fireproofing along with steels which form tenacious rust surfaces have helped steel to gain increased application. Impregnation of wood with plastic monomers polymerized in situ by chemical means or by penetrating high-energy radiation can greatly improve the properties of wood. The use of plastics as building materials is rapidly increasing. Today, they are being used, or being considered for use, for floor and wall coverings, durable finishes, piping, hardware, and insulation, to

name a few. Sealants have become important in building, especially for field jointing of panels. High-strength mortars have made it possible to build brick panels for prefabricated construction. New developments have also been made in glass, ceramics, and brick. The use of composite materials is a new and upcoming field. Often, the combined behavior of several materials acting together provide properties that are not attainable by any one of the components acting alone. These are just a few of the newly developed materials, some of which have promising futures and nearly all of which have problems which must be worked out (2,6,7).

#### B.5. Systems Building

The implementation of a systems approach to the design of complex projects follows along with the innovations in building technology discussed above. Dietz (6) defines systems analysis as follows:

... it means the careful consideration of all the elements of a given problem, including both its internal structure and the features of the external environment which affect its operation.... In carrying out a systems analysis or systems design, as each step is taken and as each factor is considered, its relationships to all other factors are examined. The interactions of each move on all others are taken into account by an interactive or repeating series of steps involving feedback or reconsideration of all previous steps.

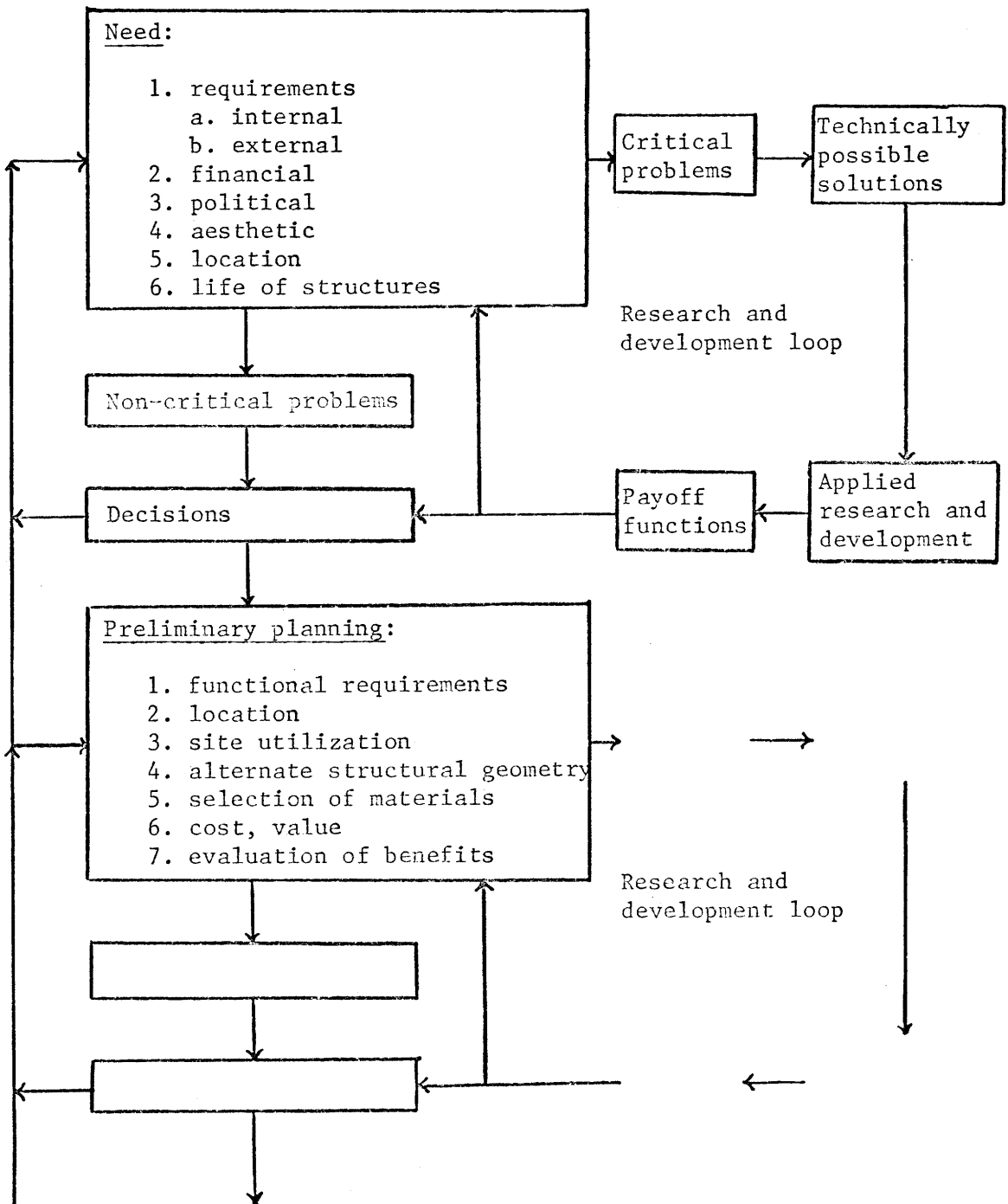
The building process is really a subsystem of a larger system involving finance, economics, public policy, social pressure, and so on. The production of a building today usually consists of three major steps: (1) program, (2) design, and (3) construction. Often the first two steps are carried out with little or no thought about

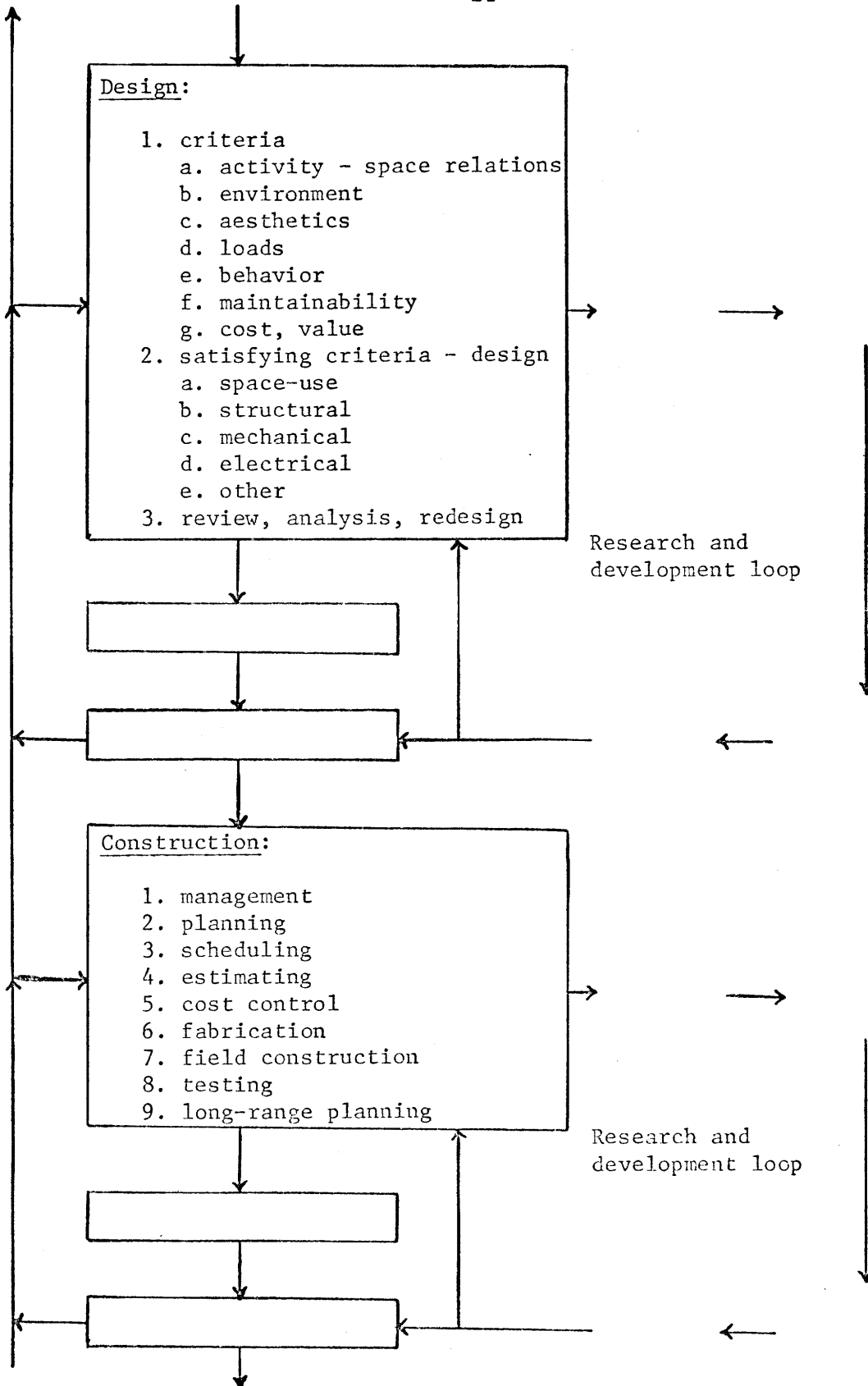
the feasibility of construction (third step). Furthermore, once a building is complete the designers and builders generally leave and never try to determine how the building actually performs (6,7).

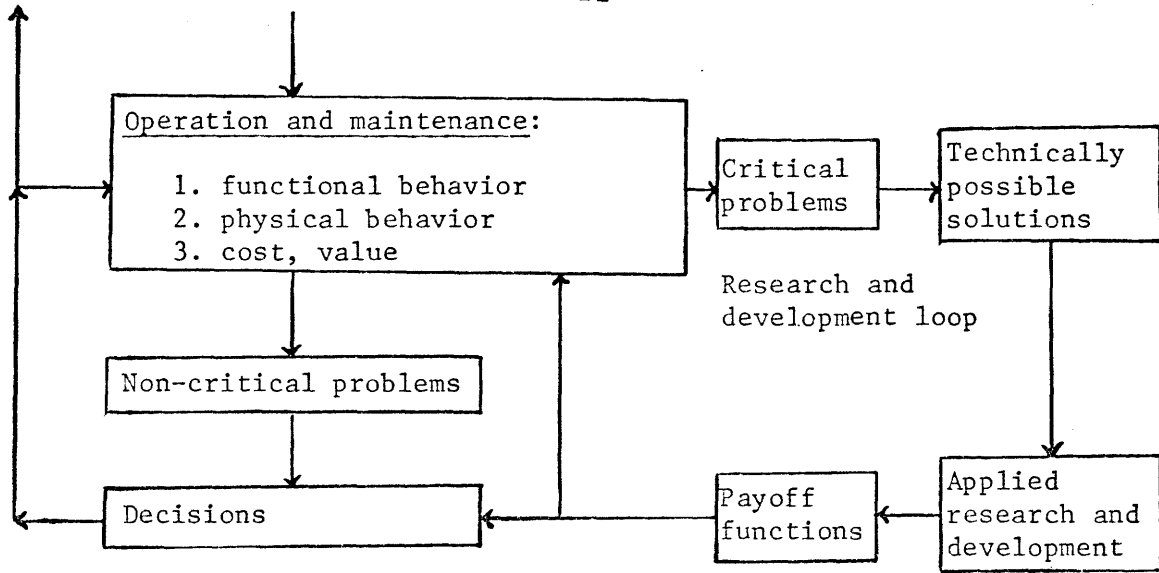
In order to be more satisfactory and useful today, Dietz (6) feels that the building process should be much more comprehensive and should involve these steps: (1) need, (2) preliminary planning, (3) design, (4) construction, and (5) operation. Each of these steps, in turn, is connected back to each of the preceding ones by a feedback loop since each step influences earlier steps which may have to be modified. Furthermore, the experience gained should feed back into preceding steps in order to be utilized in the design of future projects. There are non-critical and critical problem blocks associated with each step as well. A non-critical problem is one for which a decision can readily be made and the results fed into the next step and back to the preceding step to check for any alteration of the factors. A critical problem is a more complex one which requires a program of research and development. The results of this research are then fed back into the decision block and into the preceding main block to determine the possibility of changes. Figure 1 gives a more detailed description of what is involved in each of the five main blocks.

As mentioned previously, the first four steps are generally carried out today with some interactions among them but certainly not enough. Furthermore, feedback, to the preceding steps for future work, from the last step (operation and maintenance) is virtually

FIGURE 1: DIAGRAM OF SYSTEMS APPROACH TO BUILDING (6)







nonexistent. In summary, Dietz (7), along with many others, feels a total systems approach is necessary and must integrate the functions carried on in a building, involving structure, environmental controls, aesthetics, internal transport, utilities, efficient construction, operation, and maintenance, into an optimum solution.

#### B.6. Constraints on Technology

One of the major reasons innovations are so slow to come about in building technology, be it a change in actual construction aspects or in the general approach to building, is that people have been building and organizing construction in a conventional manner for so long that they are reluctant to change. There is no generally accepted method today in the U.S. by which innovations in housing technology can be collected, certified, and made generally available. An innovator has a hard time getting his idea evaluated and accepted, and progress is so slow that many good ideas die before they can prove themselves. In Europe, many countries have set up a system of evaluation and certification patterned after the original French Agrément procedure. It seems that such a system might also be applicable in the U.S. (7,18).

Building codes and specifications are based upon detailed descriptions of how to build and tend to discourage innovation. Cooperation from local building departments in enforcing codes on the basis of a statement of objectives, or performance, could alleviate this constraint. This leaves it up to the designers and builders to produce a system of construction, innovative or not, to meet the perfor-

mance requirements. Such a change would require a complete revision of building codes, but this would probably be a good thing because there are other problems with them as well (e.g. local variations and lack of updating) (6,7,17).

Even if an innovation has been approved, it may be difficult to get it produced if it does not conform to established industrial patterns. This is especially true for innovations in composite materials and combined systems and subsystems which call for coordination of materials and/or equipment. This might require collaboration on the part of several industries or expansion of one industry into unfamiliar areas, and this runs into several problems, ones with labor unions and codes among others (7,17).

Many innovations, particularly those involving changes in the actual method of building (e.g. prefabrication and subsystem service cores), require much more organization and control of construction than have been employed in the past. It seems the most successful European industrialized systems are the well organized and well managed ones. Economies and cost reductions are largely a result of efficiency and speed in building which can only be achieved through careful project management, organization, and control (7).

Labor is another major constraint on recent trends in building technology. Craft union organization today does not really fit innovations involving prefabrication or combinations of materials and functions. Wages of skilled labor are so high that a major reason for innovation is to try to minimize on-site construction and to substi-

tute unskilled labor, in factories and even on-site, for skilled labor. This has been done in Europe to some extent and seems quite successful, but at the same time it creates many problems with labor unions which, in turn, create problems on the building site (6,7).

Government policy also strongly affects building and building technology. Many of the newer technologies require quite large investments in plants, and before anyone will be willing to do this, he will want to be certain of having a fairly steady market which, of course, is largely dependent upon government programs, especially in building (7,17).

Last, but not least, is the problem of public acceptance of innovations. The public tends to be rather reluctant to accept unfamiliar technologies and new applications of materials perhaps because of previous failures which they have witnessed and because they would rather be sure of how well something will function by having observed its operation in previous applications (7,17).

#### B.7. Research

In order to find answers to these problems of technology and its constraints, further research is necessary. Research has been quite extensive in materials and equipment but rather spotty in areas having to do with performance (physical and functional) of buildings, design as a total system, prediction of behavior, and human reactions to buildings. Furthermore, dissemination of information pertaining to research has also been less than satisfactory. This makes it difficult to know where work has been done and where more needs to be done.

Research should be encouraged, of course, and Dietz (6) feels this might best be done by developing a central research facility which carries on in-house research itself, collects and distributes research information, and supports research at universities, private research agencies, industrial facilities, and other government agencies (6,7).

### C. Social Aspects of Housing

Given a specific housing facility, a user is anyone affected by it and one to whom its importance varies directly with the importance of the function it serves. Users may be categorized into four types: direct, indirect, external, and potential. Direct users\* are residents of the housing, and it is for them that housing is usually designed. Residents of the immediate community make up the indirect users, and for them, the housing can have a certain social impact on the community and perhaps provide some physical facilities. External users include financial backers, builders, owners, city officials, and community leaders, each of whom has an interest in the housing through his work, its economic importance, or its relation to his political power. Potential users, finally, include everyone who might, in the future, be one of the three preceding user-types. These four user groups are quite distinct from one another, but they do interact a good deal as shown in Figure 2 (16).

Maslow suggests that the following are the basic human needs:

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\* note: In this paper the term "user" will mean the direct user while the other levels of users will be referred to by their full names.

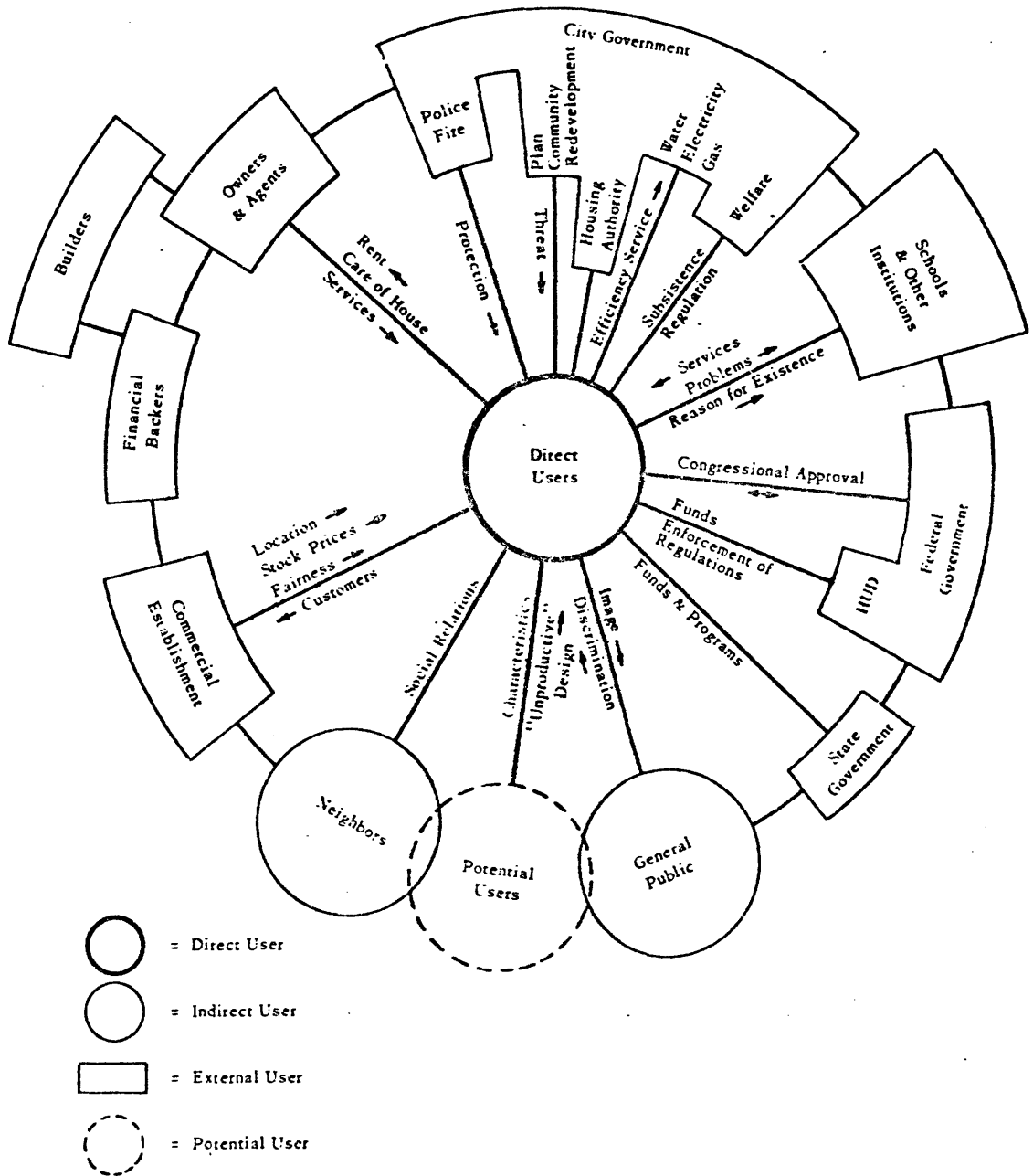


FIGURE 2: HOUSING USERS AND THEIR INTERRELATIONS (16)

survival, security, social, self-esteem, and self-fulfillment. These same basic needs underlie the specific needs relating to housing. Further, the list is in hierarchical order of importance beginning with survival at the top (1,16).

Housing provides shelter and thereby satisfies a need of survival. The protection of housing gives a person the necessary feeling of safety and security. Housing also contributes to satisfaction of higher, psychological needs. Thus, self-esteem and social needs are affected by the way in which a user's housing presents him to others. Finally, satisfaction of the basic physical needs and of the higher, psychological needs results in a higher degree of self-fulfillment (1,16).

Housing, which is successful in meeting basic physical user needs, will permit the expression of higher level, psychological needs. It is these higher level needs which are difficult to satisfy, and housing which satisfies the physical needs may or may not be successful in satisfying the psychological ones.

The In-Cities Experimental Research and Development Project (16) did several studies on user needs in 1969. Their findings, which serve to illustrate the basic physical and psychological user needs, indicate that the major low-income housing requirements in cities are as follows: (1) an increased variety of units to provide the user with more choice in choosing his housing, (2) units to accommodate different life styles, (3) units adaptable to changing needs, (4) increased concern for physical integration of the housing with the

existing surroundings, (5) flexibility of present standards and regulations, (6) more skilled design of such projects with some creative interpretation of needs, and (7) increase in user control and involvement (that is, trying to give the user more control of housing design and of management of the completed project and perhaps even involving him in the actual construction phase; this is in order to encourage him to take care of his home). These, then, summarize the basic low-income user needs which building today should be striving to satisfy (16,28).

#### D. Economic Influences on Housing

The housing industry is a large and diffuse industry sensitive to many influences, including those of technology of housing design and production, building codes, government financial policies, land, labor, markets, and the industry's own coordination. Improvements in any one of these factors alone cannot solve the problems of producing, operating, and maintaining housing efficiently, in large volume, and at minimum cost. All aspects of the system must be worked on simultaneously, for developments in each strongly affect the others (6).

The technology of housing and problems with building codes were thoroughly discussed in a previous section of this chapter. The other influences on housing will be considered now.

##### D.1. Government Financial Policies

Government financial policy can have a profound effect upon the housing picture. In the area of taxes, fluctuations in income and

real estate taxes can greatly encourage or discourage private investment in housing. Investors are naturally interested in a high return on their investments, and the higher the taxes they must pay, the lower their return and the higher the rent they will have to charge. Property taxes alone for privately owned, rental apartment buildings went up 9.2 percent from 1966 to 1969, having represented 15.2 percent of the gross possible income from the buildings in 1966 (6,9).

As for interest rates, fluctuations in rates on construction loans naturally have a considerable influence on the amount of housing construction while variations in rates on mortgages for new and used housing affect the feasibility as well as desirability of investment (6). High interest rates result in decreased new construction, rehabilitation, and investment which, in turn, cause an even greater housing shortage and higher rents. In fact, according to the report of the President's Committee on Urban Housing (27) in 1968:

Financing costs for housing -- principally the interest rates on mortgages -- are perhaps the most important single variable which determines monthly housing costs.... At present, a 1 percent rise in the interest rate is equivalent to as much as a 10 percent rise in the initial cost of a house.

The In-Cities Experimental Housing Research and Development Project (2) estimates that only about a quarter of a family's monthly housing cost goes for the land and building; the other three-quarters goes for interest, property taxes, insurance, maintenance, and other expenses. The President's Committee believes that the availability of more flexible underwriting criteria for federal mortgage insurance programs (authorized in the Housing Act of 1968) should help to lower

debt financing costs in central city areas and for minority group purchasers. Furthermore, they feel that greater reliance on fiscal policy, instead of monetary policy, to counter inflationary pressures in the economy should help to keep interest rates down.

Even with the introduction of lowered and stabilized interest and tax rates, private enterprise alone cannot solve the low-income housing problem. Federal housing assistance, in the form of direct or indirect subsidies, is essential for these low-income families (19,27). According to a study done by Eaves (9) in 1969, subsidizing interest rates on rental and cooperative housing, which reduces the effective rate to owners to three percent (depending upon conditions, to as low as one percent), is proving to be an effective stimulant to housing.

In summary then, it can be seen that the housing industry is subject to great uncertainties as government financial and fiscal policies change. This, of course, can quickly aggravate the fluctuations in construction activity instead of leveling them as government policy should (6).

#### D.2. Land

The high cost and limited availability of suitable land create major obstacles to the development of housing projects. As if this was not enough, many communities, in order to decrease the chance of having low-income housing in their area, enact rigid zoning and subdivision regulations which further raise the cost of land and its development. In order to achieve low-cost housing, more efficient

use of land is undoubtedly necessary, and this is probably best done by increasing population densities and loosening such restrictive community regulations. In downtown urban areas, where little or no commuting to work is necessary, it is often virtually impossible to assemble parcels of land suitable for housing, without government intervention and assistance. Even with such assistance, it often remains an impossible task (6,17,27).

### D.3. Labor

Housing is a rather labor-intensive commodity and is thus influenced by the ever-increasing wages demanded by the skilled building trades, but not to the extent that most people think it is affected. Construction labor rarely accounts for more than one-quarter of total initial production costs (27). Furthermore, many of the technological innovations discussed previously have been aimed at replacing some of the on-site, skilled labor by off-site, unskilled labor whose wages are lower. Skilled labor still insists that because of the seasonality of the industry, hourly wage rates must be high in order to provide a reasonable annual income. A reduction of such seasonality through innovations in building, a lengthening of the construction season, and the use of some trainee labor during the peak season should help the housing industry in reducing overtime and other premium payments to workers during the peak season. Many of the union work rules also add to the problem of labor costs because they bar the use of some labor-saving tools and innovative technologies

and may even limit the amount of work to be done per day (2,6,17,27).

If workmen had the prospect of fairly steady employment throughout the year, it seems likely that it would be possible to increase the flexibility of the work force and lessen its reliance on these old rules. Furthermore, with better supervision and utilization of manpower on the job-site, productivity could certainly be somewhat increased at only slightly higher wages if not the same. In summary, it seems that though labor costs definitely have an impact on housing, it is not as great an impact as some of the other factors have (2,6,17,27).

#### D.4. Housing Market

Though the demand for housing is very high at present, the housing market varies greatly from year to year and from season to season in any given locality. A stabilized market is a much more desirable one from the viewpoint of the housing industry because a level demand means steady employment and production and reduces the risks of large capital investments or creation of large permanent organizations. Public policy affecting construction should encourage the leveling of private building to the fullest extent and should use public construction as a further means of leveling building activity by shifting public building from season to season, or even from year to year, to suit the building need (6).

#### D.5. Housing Industry's Coordination

The housing industry is a rather loose aggregation of small

to large firms, each performing only one of the major operations that result in the production of housing. When an investor wants a structure built, he picks out a team of the necessary specialists (e.g. in the areas of land development, finance, design, and construction) who work together until the project is completed. Through the use of a different combination of specialists for each project, a good amount of flexibility is introduced. Differences among various housing projects can be accommodated by putting together the perfect combination of specialists for each particular project (6, 27).

At the same time though, this flexibility results in inefficiency and delay in production. Consequently, steps toward closer coordination of the specialties are being taken. Architecture and engineering offices are joining together to combine the various aspects of design, and teams of specialists are becoming more organized. Often, in fact, the construction consultant is brought in at the start of the design process, instead of after its completion, in order to achieve close coordination of all stages in housing production. Even some vertically-integrated firms are beginning to emerge (6,27).

#### D.6. Summary of Suggestions for Cost Reduction of Housing

Technology, building codes, government financial policies, land, labor, markets, and coordination of the housing industry all have an influence on the housing industry and the cost of

housing. The President's Committee on Urban Housing (27) concludes that the main methods to use in achieving reduction in the cost of housing, without any sacrifices in quality, are policies to: (1) eliminate any existent impediments to innovation and cost reduction, (2) encourage research and development activity, (3) stabilize patterns of construction, and (4) create new institutions, such as a testing institute, which a high level technology housing industry would need.

The President's Committee estimates that relative monthly housing costs should be reduced by at least ten percent by such policies in the next few years. The size of the possible reductions would vary, of course, from place to place and from item to item. While a cost reduction of ten percent seems small, the annual amount of new housing construction is so large that this reduction would save billions of dollars of resources a year.

## Chapter II

## PURPOSE, OBJECTIVES, AND SCOPE OF RESEARCH

A. Purpose

As the demand for low-income, government subsidized housing increases, the need for a method of analyzing the costs involved in housing increases as well. It is felt that a total cost model, consisting of submodels of initial development, operating, and user costs, should help to satisfy this need.

Such a model may be useful to people in government and in the building industry by helping them to evaluate the alternatives available in building single- or multi-family, low-income housing. Further, it may help the user and private investor to see where their money is going and what their expenses and profit may be. In these ways, then, a total cost model should help to analyze housing costs.

B. Objectives and Scope

The long-range goal of this research is to do a total cost analysis of low-income, government subsidized housing. As indicated previously, the plan is to develop a total cost model, for single- or multi-family dwellings, which consists of submodels of initial development, operating, and user costs. Given a set of conditions for housing then, it is expected that one will be able to determine the costs, present and future, of the various possible combinations

of alternatives and choose the option which best suits his needs.

The logical place to begin in developing a total cost model is at the beginning with the initial development cost submodel. The framework of such a model, including land, construction, and related costs, for single-family housing, is the immediate goal of this research.

It seems reasonable to limit the scope of the study to the initial development cost model because the factors involved in the initial development of a dwelling provide such a vast array of alternatives. By considering some of these alternatives, the model can help one to make decisions, among others, about just what it wanted in the house and what can be eliminated (e.g. basement or fireplace) and about the desired quality of materials and construction (e.g. high quality may be expensive initially, but it may be more economical than low quality in the long run because of the savings in maintenance). Alternatives in land cost and trade-offs between land cost and construction or related costs may also be of interest (e.g. an expensive site with more desirable soil conditions may result in a less expensive house because of savings in foundation costs). Furthermore, in order to develop various maintenance and user plans and to evaluate these plans in terms of the available trade-offs between initial and future costs, the structure itself, the major outcome of the initial development cost model, is needed.

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Only single-family, conventionally constructed homes are being considered at first for the sake of simplicity. It is easiest to begin with these and later include more innovative building techniques. Finally, these will all be grouped together to make up multi-family dwellings.

## Chapter III

## MICROECONOMICS OF HOUSING

A. Where the Costs in Housing Accumulate

In order to do a total cost analysis of low-income housing, one must first know where the money in housing goes. Just what it costs to build and operate new housing for an American family of any income level is difficult to determine, but it is not so hard to get an idea of what factors cause these costs.

As stated in Chapters I and II, the total cost of housing can be divided into three major categories: initial development, operating, and user costs. Through the use of several references and by talking to some builders, it was possible to determine the individual costs involved in each category. These costs are most clearly expressed via the outline given below (5,9,13,19,23,30,31,33):

## I. Initial development costs

## A. land cost - acquisition

## B. construction costs

## 1. site development (materials, labor, equipment)

## a. clearing lot

## b. soil tests

## c. preparing lot for foundation

## d. bringing in services

- e. driveway and sidewalks
- f. landscaping
- 2. structure construction (materials, labor, equipment)
  - a. foundation
  - b. floor
  - c. exterior walls
  - d. interior walls
  - e. roof
  - f. heating and ventilation
  - g. electricity
  - h. plumbing
  - i. appliances
  - j. painting and finishing
  - k. miscellaneous
- 3. miscellaneous extra construction operations
  - a. utilities used in construction
  - b. clean-up
- C. related costs<sup>\*</sup>
  - 1. overhead and profit
  - 2. architect and consultant fees
  - 3. administrative

---

\* note: Real estate taxes have not been included because they vary so much from community to community. Furthermore, there is often considerable question about whether or not taxes should be included since they constitute a transfer payment and not an economic cost (2).

4. permits and legal fees
5. financing
6. insurance during construction
7. performance bonding

## II. Operating costs<sup>\*</sup>

- |                                   |   |                             |
|-----------------------------------|---|-----------------------------|
| A. heat and utilities             | } | (those covered by operator) |
| B. maintenance                    |   |                             |
| 1. upkeep                         |   |                             |
| 2. repair and/or replacement      |   |                             |
| C. financing and debt service     |   |                             |
| D. insurance                      |   |                             |
| E. depreciation                   |   |                             |
| F. management                     |   |                             |
| G. vacancies and delinquent rents |   |                             |

## III. User Costs

- |                          |   |                                 |
|--------------------------|---|---------------------------------|
| A. user is renter        |   |                                 |
| 1. real costs            |   |                                 |
| a. rent                  |   |                                 |
| b. heat and utilities    | } | (those not covered by operator) |
| c. maintenance           |   |                                 |
| 2. psychological costs   |   |                                 |
| a. inability to pay rent |   |                                 |

---

<sup>\*</sup> note: See note on previous page.

b. dissatisfaction with housing and its facilities

c. dissatisfaction with community

B. user is owner

1. real costs - included in operating costs above  
 (all of section II excluding parts F and G)

2. psychological costs

a. inability to maintain and finance the housing

b. dissatisfaction with the housing and its  
 facilities

c. dissatisfaction with the community

This outline gives a good general picture of where money in housing goes. In order to do any kind of a reasonable cost analysis, considerably more detailed information is required. As mentioned in Chapter II, the model framework proposed in this thesis limits itself to initial development costs for conventionally built, single-family housing. Further detail on the operations and costs involved in building such housing is given in the next section as well as in Appendix A and Chapter IV.

B. Distribution of Costs in the Initial Development of Conventional Housing

There is a distinct lack of sound statistical data on actual costs of housing, and even data for individual projects is very difficult to find. Some records are kept on estimated building costs, but even these are not terribly useful because every builder defines costs differently and rarely clearly explains just

what costs he is including in his aggregated sums. Furthermore, costs of various parts of dwellings vary from builder to builder as well as from locality to locality.

In searching for the distribution of costs among the various initial development expenses, it was discovered that data for costs distributed as in the outline in the previous section is simply not available. Much information can be found which is based on cost per square foot of floor area. Such costs are so aggregated that they are insensitive to simple changes in materials and methods of construction and are of little use in evaluating trade-offs between initial and future costs that result from different maintenance requirements of materials. For these reasons, it seems such costs would be of little use in the model.

It was also found that there is some information available on actual builders' prices. These costs, too, are very aggregated. One can get a general picture of how much of the money goes into the site, how much into the structure, and how much into each of the related costs, but what one cannot see is where the money goes within the construction of the house, and this is just what is needed in the model. Table 1 shows some distributions of these costs obtained from various references. The differences between them are likely due to the fact that every builder defines each of these categories somewhat differently and that the figures are from different builders and parts of the country.

TABLE 1: DISTRIBUTION OF INITIAL DEVELOPMENT COSTS FOR CONVENTIONALLY  
CONSTRUCTED, SINGLE-FAMILY DWELLINGS (IN PERCENTAGES OF TOTAL)

	Herrey (13) (estimated costs)	Huson (15) (average actual costs)	Pres. Committee (27) (estimated costs)	Eaves (9) (average actual costs)	Eaves (9) (average actual costs for 4 builders (NE,W,MW))	Eaves (9) (average actual costs for 1 builder)	
A. land		18.7	25		(23.2)	(21.2)	
1. acquisition	9.1 <sup>1</sup>			15.6	13.8	7.0	
2. development					9.4	14.2	
B. construction costs	(57.9)	59.6	(55)	68.8	53.8	53.2	
1. materials	38.6		36				
2. labor	19.3		19				
C. related costs	(33.0)						
1. overh'd.&profit	14.2	} 14.6 <sup>2</sup>	14	6.2 <sup>3</sup>	13.7 <sup>4</sup>	16.8 <sup>6</sup>	
2. permits & legal	1.5						
3. arch.&cons.fees						1.3	1.6
4. insurance	5.1						
5. perf. bonding	6.1		6	6.3			
6. administrative	6.1	7.1		3.1	8.0 <sup>5</sup>	7.2 <sup>7</sup>	
7. financing							

subtotals are bracketed ( )

<sup>1</sup> includes demolition as well

<sup>2</sup> job overhead 2.1%  
general overhead 4.2  
builder's profit 8.3

<sup>3</sup> indirect construction 3.1%  
profit 3.1

<sup>4</sup> supervision 4.5%  
gen'l. overh'd. & profit 9.2

<sup>5</sup> financing 3.5%  
mortgage points 4.5

<sup>6</sup> supervision 7.2%  
gen'l. overh'd. & profit 9.6

<sup>7</sup> financing 2.3%  
mortgage proc. & clos. 1.0  
mortgage points 3.9

More detailed breakdowns on structure costs are difficult to obtain. Of those given in Table 2, one is from a report by Eaves (9) and the other is from a builder (31). Many builders do have records of costs similar to these but are unwilling to release them. Even these costs though do not give the information required by the model.

It seems that if costs for the various phases of construction (e.g. site development, foundation, and floor) are desired, one must work them out oneself through the application of unit costs to real house designs (see Chapter IV, section C.1). This should not be at all difficult for a builder who is experienced in house construction and cost estimating and who has his own sample house designs. These costs, expressed as costs per square foot of wall, floor, or ceiling area for each major step in each phase of construction, are aggregated enough so that they will be easy to work with but are not so aggregated that they will be insensitive to alternatives in materials, design, and maintenance. Furthermore, such aggregated costs would facilitate an extension of this model, at some later date, to include prefabricated housing. It seems it might be reasonable to consider modifying this first model to include, for example, prefabricated, load-bearing wall panels within the exterior wall system. This would seem to be an easy way by which to look at the trade-offs between conventional and prefabricated construction.

TABLE 2: DISTRIBUTION OF STRUCTURE COSTS FOR CONVENTIONALLY CON-  
STRUCTED, SINGLE-FAMILY DWELLINGS (IN PERCENTAGES OF TOTAL)

	Fuchs (31) (actual costs)	Eaves (9) (average actual costs for 4 builders (NE,W,MW))
A. foundation, frame, shell	(58.0)	(58.4)
1. foundation	5.7	9.7
2. lumber (includes glass)	21.9	16.4 <sup>4</sup>
3. carpentry	18.2	22.8 <sup>4</sup>
4. sheet metal		0.6
5. masonry	9.4	2.8
6. roofing		6.1
7. insulation	0.9	
8. garage doors	0.5	
9. structural steel	1.4	
B. interior finish	(20.4)	(19.2)
1. painting (int. & ext.)	4.4	4.8
2. drywall/plaster	5.2	8.3
3. hardware	0.7	1.3
4. bathroom walls		1.3
5. flooring	6.2 <sup>1</sup>	3.5
6. cabinets	3.9	
C. mechanical subsystems	(19.8)	(19.0)
1. plumbing	10.3 <sup>2</sup>	8.7
2. heating	6.3 <sup>3</sup>	5.9
3. electrical	3.2 <sup>3</sup>	4.4
D. appliances	1.8	3.4

subtotals are bracketed ( )

<sup>1</sup> vinyl 0.2%    <sup>2</sup> plumbing 6.6%    <sup>3</sup> wiring 2.6%  
 tile, slate 1.7    septic system 3.1    fixtures 0.6  
 carpet 4.3    water 0.6

<sup>4</sup> includes cabinets

## Chapter IV

## STRUCTURE OF INITIAL DEVELOPMENT COST MODEL

A. Cost Models in Existence Now for Housing

The need for a method of cost analysis of housing, as discussed in the first chapter, as well as the increased use of computers, has resulted in the development of several computer-based, designing and cost-estimating, housing models in the last couple of years. Those of greatest interest, which have to do with initial development costs, are briefly discussed below. A few others, of a more general and theoretical nature, are just referenced (12,21).

A.1. O'Block and Kuehn (26)

The Housing Analyzer Model (HAM) developed by O'Block and Kuehn considers initial development and operating costs and, to a limited extent, user cost. It is a computer simulation program designed to serve both private investors and public policy makers equally well. In fact, it has been in use in a large public agency for over a year on a time-sharing computer system.

The principle upon which HAM is based is that for a housing project to be economically feasible, interest and amortization costs associated with planning and construction (new construction or rehabilitation), plus operating expenses, must be less than or equal to the aggregate rent (project income) which, of course, must be less than or equal to the occupant's ability to pay. The model generates the economic consequences of alternative assumptions about policies,

programs, costs, and so on, once these assumptions have been input. The output, then, gives the decision maker some basis for judgment among the alternatives. In this judgment, he must also consider the social, political, and aesthetic factors which have not been included in the model.

HAM consists of a general main program which computes the basic costs as discussed above and several subroutines which can be helpful in analyzing some more complex issues if desired. A couple of the issues for which subroutines have developed are as follows: (1) what is the optimum holding period for a given housing investment with given conditions and (2) what is the relationship between the increased cost of higher quality materials and construction and the better tax shield generated by a longer-term mortgage. These are only a couple of the available subroutines, and additional ones for analysis of special situations can quite easily be developed and plugged into the program.

HAM is concerned mainly with the general economic aspects of housing and with testing broad policy issues. It uses very aggregated costs (e.g. construction cost per square foot and operating cost per room per annum), but its developers are working on obtaining more detailed cost data for future use. At present, HAM is useful for giving indications of cost structure sensitivity to selected subsidy programs and cost variations, but the total cost model discussed in this thesis is concerned with more accurate calculations of dollar values and the trade-offs between construction and mainte-

nance costs or user costs. Thus, this model will use much more detailed cost data than does HAM. Also, in the user cost model, the author is interested in trying to include some of the psychological factors in terms of cost. HAM will prove to be most useful, however, for the basic economic aspects.

A.2. Kramer and Shaffer (20) and Daniels (4)

Kramer and Shaffer developed a computer-based estimating procedure (COBESTCO) to increase the speed and accuracy of the estimating process in the construction industry today. COBESTCO has been designed such that any construction firm, regardless of its size or the size of its projects, can use it. The Critical Path Method is used as the mechanism for treating the construction process in as much detail as desired in the estimation procedure. Each simple construction activity is uniquely defined according to types of work, location, and time and duration of execution. Each operation is then broken down into several estimating units, for which prices are computed using production rates, crew composition, and wage rates along with equipment and materials costs. This breakdown serves simultaneously as a basis for cost estimating and for construction scheduling. COBESTCO gives the estimator an opportunity to apply his own judgment in any of the operations which the computer performs. Another convenient characteristic of the system is that it will take input data in any form and convert it to the units which the system uses.

Daniels developed a system, based on COBESTCO, which takes care of a contractor's estimating and accounting needs. By using specially designed "time-and-materials-installed" reports from the construction firm's field records, this system is capable of creating and maintaining a basic set of cost and time information which can be used in pricing and scheduling future work. This basic cost library can be updated at any time with information from the field. Furthermore, Daniels' system performs payroll calculations and keeps an accounting of money that is spent.

The purpose of both COBESTCO and Daniels' system then, is to provide a construction firm with a method of cost-estimating and scheduling projects. COBESTCO does this using a static cost library whereas Daniels' model uses a library based on the past experience of the firm (information from accounting records) and one which can be updated at any time. The cost library that the author intends to use for the initial development cost model would be one more like Daniels'. Both COBESTCO and Daniels' system require a large amount of highly detailed input from the user because they are looking for exact estimates. Since the purpose of the model discussed in this thesis is to look at trade-offs between initial development and operating or user costs, somewhat more aggregated costs could be used so that the person using the model does not have to input so much data. It seems that the type of costs desired in this model is between that of O'Block and Kuehn's model and that of Daniels'.

### A.3. Mogel (25)

The preface of Mogel's report points out that in current practice, building design requires the activities of various specialists who restrict their attention to only parts (e.g. structure, plumbing, heating and ventilating, electricity, or vertical transport) of the total building. A computer approach to building design must work the same way. The idea is to suboptimize each part of the building for a given set of conditions and objectives and then to evaluate all of these suboptimal component designs in view of the overall building objectives, issuing a new set of conditions and objectives for each of the parts which, in turn, produce new designs. This process is iterated until a satisfactory design is obtained.

To test the feasibility of such a computer system, Mogel developed a preliminary design model for building service supply systems. The major design objective is to get a high rate of return on investment. The purpose of the model is to arrive at a quick estimate of the optimal configuration and the minimum cost of low-income urban housing obtainable under a given set of conditions. In this way, the system could be used for a preliminary economic feasibility evaluation of sites and proposed projects, to determine whether or not a building would be economically justified at the minimum possible cost.

The total cost model being considered in this thesis does not really involve such optimization features; that is, there is no real

objective which one is designing for and trying to optimize. The purpose of the model is to present the designer with the various costs and trade-offs and to let him choose the design which best suits his needs (e.g. someone might be willing to accept higher initial development costs in return for lower operating and user costs).

#### B. Cost Models in Existence Now for Other Construction

Other people in the Materials Division of the M.I.T. Civil Engineering Department have also worked on cost-estimating models. Two of these, which were particularly useful in arriving at the housing model, are discussed below.

##### B.1. Highway Cost Model (24)

The main purpose in creating the highway cost model was to develop a method of predicting costs and future behavior of alternative highway transportation strategies. The satisfactory measure of desirability was defined as the minimization of total transportation cost (including construction, maintenance, and user costs) in terms of present worth. As stated earlier, the housing model does not really have such a measure of desirability; it is left up to the model user to choose what he wants to optimize. Furthermore, the highway cost model necessarily assumed that the traffic demand is perfectly inelastic; that is, for an individual project there is a given demand function. Such a demand function is not present in housing (i.e. if the cost of the housing is too high, people simply

will not live there).

The overall framework of the highway cost model was used as the basis for the housing model. The highway model consists of submodels which compute construction, maintenance, and user costs for each year of the study, based on the input conditions for a given project. These costs are totaled and discounted to find the present value of the total transportation cost for the strategy specified. Thus, the person using the model can evaluate a series of strategies on the basis of their predicted total costs. In this way, the submodels can interact, and one can see the trade-offs between construction, maintenance, and use of the road. The cost estimates, then, are based on the simulated behavior of the road during the analysis period. It is from this framework, then, that the basics for the housing cost model were developed.

#### B.2. Tunnelling Cost Model (14)

The tunnelling cost model is concerned with scheduling the construction processes as well as estimating the construction costs in order to analyze current operations and determine the economic effect of changes in design or construction procedures. The operations involved in tunnelling are highly interrelated and thus necessitate detailed scheduling of the construction. The same is true only to a limited extent in house construction; consequently, less of the housing model will be devoted to scheduling. At first, it would be desirable to consider each of the basic operations in

building a house separately. Later, it would probably be best to incorporate some scheduling into the initial development cost model to estimate more accurately the construction costs.

The general procedure which is used to compute costs in the tunnelling model is similar to that which will be employed in the housing model. In the tunnelling model detailed plans for the tunnel and a list of quantities of materials needed is computed. A list of operations to be done is next derived and ordered. After development of a table of times required for each operation, a work schedule for construction is produced. Finally from this, along with a table of wage rates, equipment costs, and materials costs and one of profit, overhead, and external costs, the cost of the tunnel construction is computed. Similarly, in the housing model, using labor, equipment, materials, and related costs and crew productivity (instead of the work schedule), the cost of house construction can be computed once the basic building operations have been outlined.

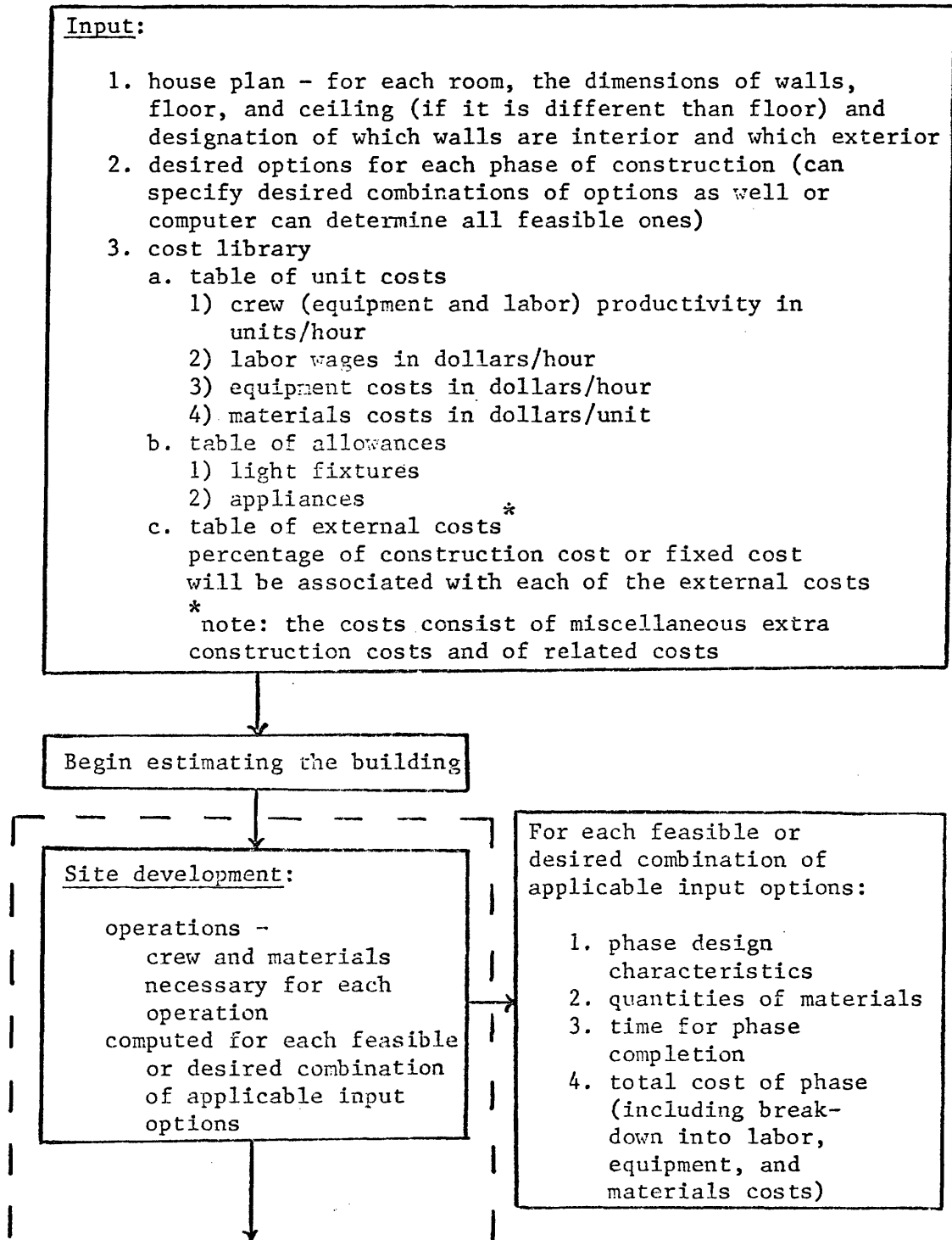
### C. Framework for the Initial Development Cost Model

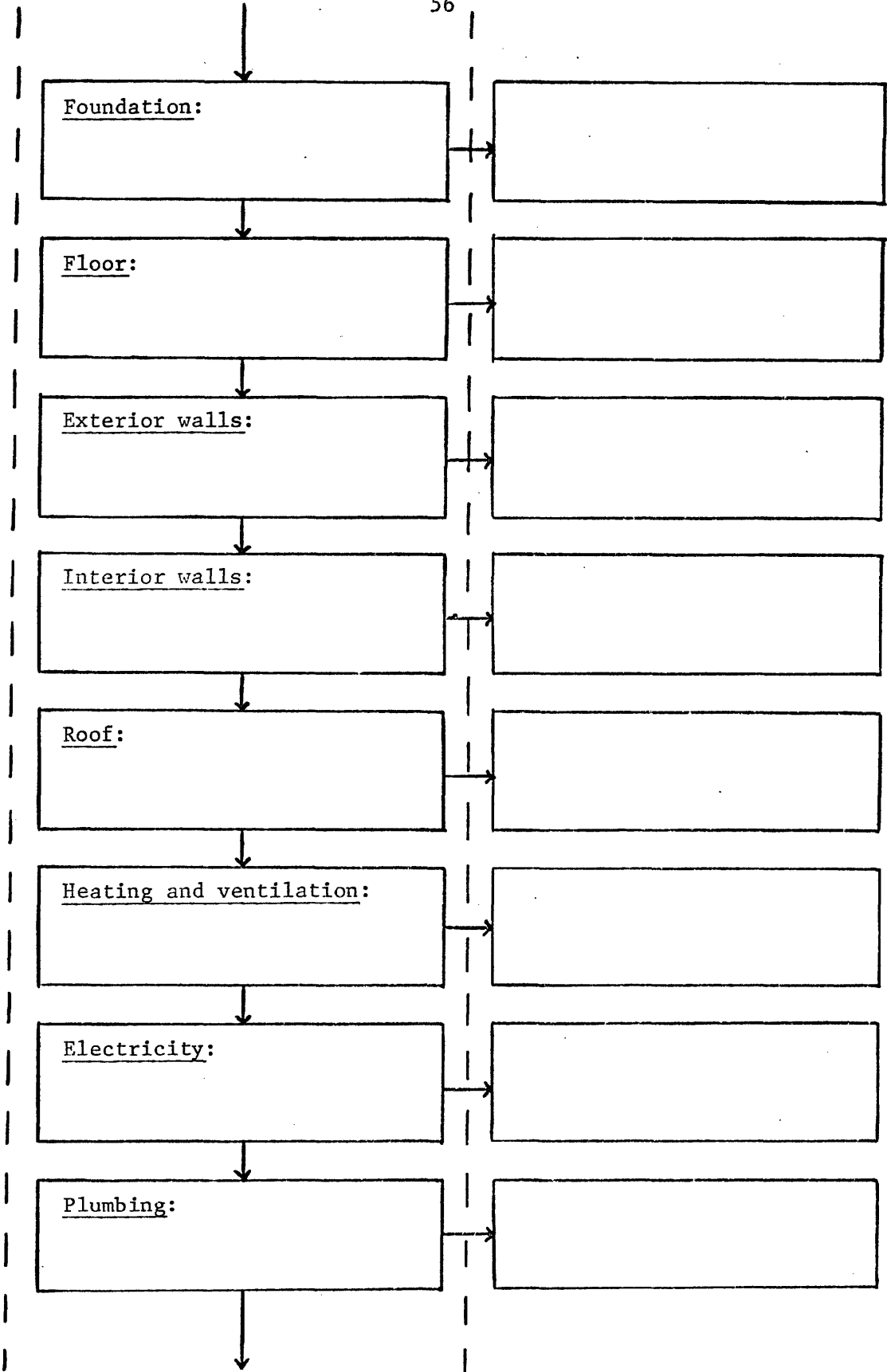
The basic structure of the initial development cost model is shown in the flow chart in Figure 3. For purposes of discussion, the model divides into two sections: (1) input and (2) model operation and output.

#### C.1. Model Input

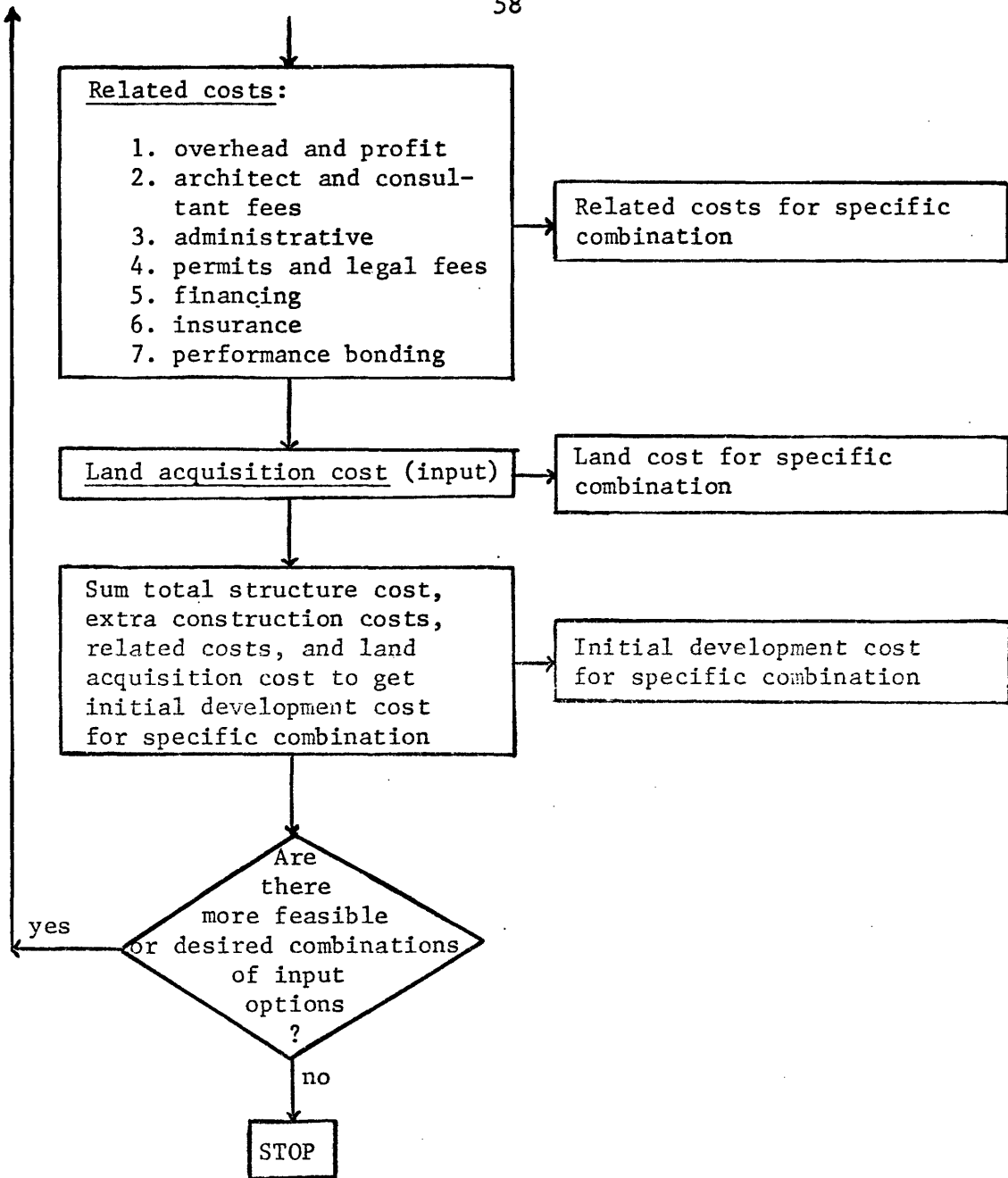
An important consideration in the development of the framework

FIGURE 3: FLOW CHART OF THE INITIAL DEVELOPMENT COST MODEL









of the model was to minimize the amount of information that the model user has to input and, at the same time, to have the model use more accurate costs than simply cost per square foot of floor area. In order to achieve this goal, three types of input will be necessary: (1) house plan, (2) desired options for each phase of construction, and (3) cost library.

The house plan should include, for each room, the dimensions of its walls, floor, and ceiling (if it is different than its floor) and a designation of which walls are interior and which are exterior. With this information, the model will be able to compute floor, ceiling, and roof area and interior and exterior wall area for each room and thus, for the whole house. Of course, these figures will be subject to modification by the size of openings for stairs, chimney, windows, and doors.

The second set of input should consist of a statement of the desired options for each phase of construction (see Appendix B for a partial list of these options). Appendix A gives a detailed outline of alternatives in techniques and materials to be used in constructing a house. The building of a dwelling has been divided into twelve phases of construction (e.g. site development, foundation, suspended floor, and exterior walls). In most of these phases, there are one or more sets of choices from each of which the model user will have to select at least one option. As the partial list of options in Appendix B shows, these choices require decisions, on the part of the model user, about what will be wanted in the house

(e.g. what type of foundation and what type of roof) and what kinds of materials will be desired (e.g. what floor finishes, what exterior wall finishes, and what interior wall finishes). By inputting more than one choice for at least some of the sets of options (e.g. what floor finishes: choice 1 is wood-strip and choice 2 is linoleum), the model user will be able to see the effects of these alternative options on the initial development cost. Trade-offs between the various alternatives in terms of maintenance and desirability will also be open to consideration once the operating and user cost models have been developed. At the present time, trade-offs between land and construction costs are also available.

In summary then, the model user will have to input his selection of options for each phase of house construction. At the same time, if he wants, he can specify for which combinations of these options he is interested in seeing the total initial development cost. On the other hand, if the model user wants to see all feasible combinations of his selection of options, then the model will determine the possible combinations and give him the total initial development cost for each.

As for the cost library, the model user can develop his own on the basis of his past experiences in house construction and input it, or he can input the cost library supplied with the model. The cost library will consist of three tables: one of unit costs, one of allowances, and one of external costs.

The table of unit costs will be based on crew (labor and equip-

ment) productivity (in units per hour), labor wages (in dollars per hour), equipment fees (in dollars per hour), and material costs (in dollars per unit). These figures will come from the experience of builders (30,31,33) and suppliers (32) and from cost manuals, such as Dodge Construction Pricing and Scheduling Manual (10) and Building Construction Cost Data (11). At least in the initial implementation of the model, these figures will be aggregated into average material, labor, and equipment costs per square foot of wall, floor, or ceiling area for each major step in each phase of construction. Different aggregated costs will also be developed for each of the options within each set, such as masonry and horizontal redwood siding within the set of exterior wall finishes. These aggregated costs will be calculated directly from the basic costs by their application to real house designs.

The table of allowances will simply consist of average allowances for light fixtures and appliances. Basic costs, used in deriving these allowances, will again come from builders, suppliers, and cost manuals. The allowance for appliances will probably be constant depending only upon which appliances are standardly included in the cost of the house, but that for light fixtures will depend somewhat upon the size of the house. Using the basic costs and a couple of typical house plans of different sizes, the light fixture allowances will be computed.

External costs consist of miscellaneous extra construction costs (including temporary light, power, heat, and water and clean up) and

related costs (including overhead and profit, architect and consultant fees, administrative, permits and legal fees, financing, insurance, and performance bonding). Miscellaneous extra construction costs generally depend upon the size and cost of the structure and are computed as percentages of the total structure cost. Some of the related costs, such as overhead and profit, are computed as percentages of total construction cost (sum of miscellaneous extra construction costs and total structure cost) while the others, such as permits and legal fees, are fixed costs. The table of external costs, then, will consist of these percentages and fixed costs for miscellaneous extra construction and related costs. These figures will be obtained from builders and cost manuals, among other references.

### C.2. Model Operation and Output

Though the framework of the model is quite well defined, the actual operation of the model is somewhat tentative. For now, each phase of the construction process will be treated as though it is independent of all others. It is still uncertain as to whether the model will be run on a batch-processing or time-sharing computer system, but for the purposes of the following discussion, it will not be of much concern.

Once the necessary information has been input, the model will begin estimating the building. The first part of the model will consist of a series of iterative subroutines, one for each phase of the building construction. The crew and materials necessary for each operation within each phase will be outlined within the appropriate

subroutine. Then, for each feasible or specified combination of applicable input options within each phase, the quantities of materials, time for phase completion, and the total cost of the phase (including breakdown into labor, equipment, and materials costs) will be computed and output along with a statement of the phase design characteristics. At this point, if the model were executed on a time-sharing system, the user could eliminate any undesirable combinations. This, of course, could not be done on a batch-processing system, but the step is not a mandatory one.

Once the various development costs for each phase have been computed, the model can sum them to get the total structure cost (including breakdown into labor, equipment, and materials costs) for each feasible or desired combination of input options. Similarly, the total quantities of materials necessary for each combination can be computed. Included within this step will be a check for any incompatible combinations of options (i.e. an indication that two phases of construction may be dependent to a limited extent). A matrix of total structure costs will then be printed. Again, at this point, the user could eliminate undesirable combinations if the model were run on a time-sharing system.

Next, one of the combinations of options will be chosen, and its total quantities of materials and total structure cost (including breakdown into labor, equipment, and materials costs) will be printed as well as its net design characteristics. Each miscellaneous extra construction cost will be computed as a certain percentage of the

total structure cost of this combination and will be printed. All of these extra costs will be summed, and their sum will be added to the total structure cost to make up the construction cost. Similarly, each related cost will be computed as a percentage of the construction cost or as a fixed cost and will be printed. Then, the land acquisition cost, which is to be input with the designation of the site and soil condition option, will be printed. Finally, the total structure cost, miscellaneous extra construction costs, related costs, and land acquisition cost will be summed to give the initial development cost which will then be printed. This procedure will be followed for each feasible or desired combination of input options until the initial development cost for each has been printed. The various costs and quantities output by this model will show the model user the effects of various alternatives on the initial development cost.

## Chapter V

## SUMMARY AND CONCLUSIONS

A thorough cost analysis of a housing project involves initial development, operating, and user costs and their interactions, which provide a very large number of variables to consider. A computer model is needed to systematically analyze the many alternative variable combinations. The initial development cost model is the first step of this total cost model. Such a computer-based modeling approach seems valid as demonstrated by the success of the highway cost model (24). As discussed in Chapters I and II, this total cost model could prove to be especially useful to the building industry, government, private investors, and users.

The initial development cost model is an iterative one. The model user must input (1) the house plan, (2) the cost library which is made up of tables of unit costs, allowances, and external costs, and (3) the desired options for each phase of construction. The user can also specify desired combinations of these input options if he cares to, or he can leave it up to the computer to determine all feasible combinations of these options. Within each phase of construction, for each feasible or desired combination of applicable input options, the quantities of materials, time for phase completion, and total cost of phase (including breakdown into labor, equipment, and materials costs) are computed. These phase development costs are then totaled for each feasible or desired combination of input options to

get the total structure cost. Miscellaneous extra construction costs and related costs are computed and added to the land acquisition and total structure costs for each combination. Thus, the desired output, initial development cost (including breakdown into labor, equipment, and materials costs for the total structure cost), is determined for each feasible or desired combination of input options. With these results, the model user will be better able to evaluate the available alternatives in construction.

At present, the initial development cost model is in its final stage of planning and should soon become operational. At first, the model will be restricted to conventionally built, single-family dwellings, but once it is operational it would be desirable to extend it to include more innovative, including prefabricated, building techniques and multi-family housing. Once this has been done, the operating and user cost models should be developed. Finally, the three models should be integrated and the total cost model produced.

## Appendix A

THE BUILDING OF SINGLE-FAMILY DWELLINGS  
- ELEMENTS OF CONSTRUCTION -

Nearly all conventional house-building done in the U.S. today is based on traditional wood-frame construction which has been used for over 200 years. Figure 4 shows how a typical wood-frame house is built using platform construction, the simplest and most commonly used system.

This appendix presents to the best of the author's knowledge, what are considered to be acceptable alternatives in techniques and materials in assembling and arranging the parts of a well designed wood-frame house. It should be noted that the quality of the specified materials, such as lumber, can vary as well. Details of construction vary from locality to locality, and even from builder to builder, but the basic principles remain the same. The order of presentation conforms to what would be the normal sequence of constructing the building if it were built in complete sections. The information is presented in outline form for clearer understanding.

Information for this appendix has been gathered from several references since no one reference seems to cover all aspects of building. If more detail is desired, one or more of the following references could be used (3,8,10,11,22,23,29,30,31).

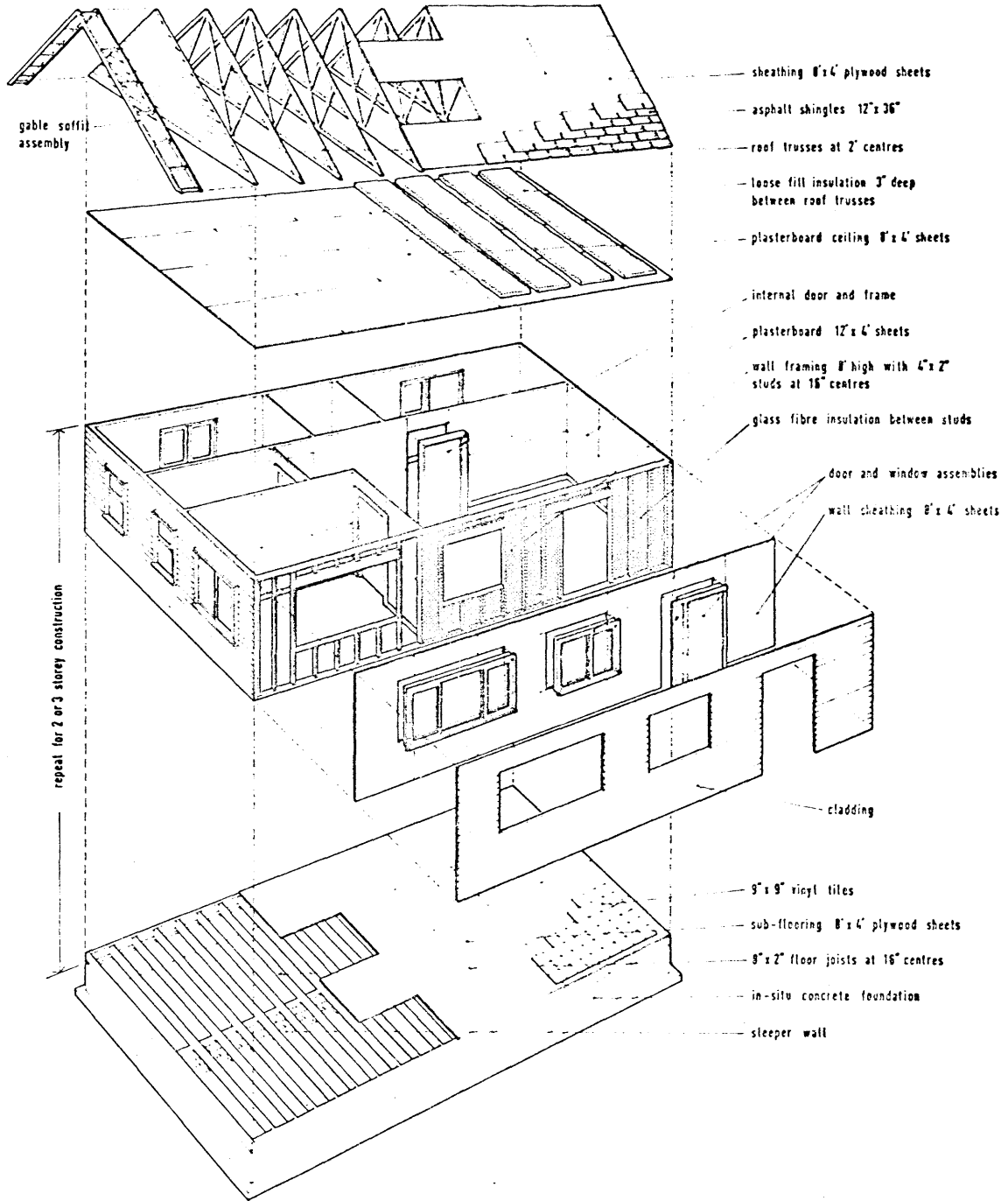


FIGURE 4: GENERAL ARRANGEMENT OF A TYPICAL WOOD-FRAME HOUSE  
 -- PLATFORM CONSTRUCTION (23)

## I. Site development

- A. clearing site
  - 1. existing structures
  - 2. natural growth
- B. stripping and stockpiling topsoil (bulldozer or front-end loader)
- C. building layout (stakes, batter boards, twine, and plumb bob)
- D. soil tests
- E. building excavation
  - 1. major excavation - to top of footings
    - a. basement (front-end loader, power shovel, or crane)
    - b. crawl space or slab (power trencher)
  - 2. minor excavation (hand)
    - a. trimming excavation
    - b. trenches
      - 1) footings
      - 2) foundation drains
- F. bringing services into house
  - 1. included with electricity
  - 2. included with plumbing
    - a. gas
    - b. sewer
    - c. water
- G. backfilling (hand)
- H. grading
  - 1. rough (bulldozer)

## 2. finish (small equipment and hand)

## I. sidewalks, driveway, landscaping - optional

II. Foundation (b = basement, c = crawl space, s = slab)

## A. concrete - ready-mix (2000 or 2500 psi) - types

## 1. standard

## 2. hi-early

## B. footings

## 1. types

a. wall footings - required for concrete block walls;  
required for poured concrete walls only if poor  
soil or if heavy building load (minimum size:  
width = 2 x wall thickness, depth =  $\frac{1}{2}$  x width)

b. column footings (b,c)

c. furnace footing

d. chimney footing - included with chimney in  
miscellaneous

## 2. materials needed

a. forms

b. concrete

C. foundation walls (height: for b:  $7\frac{1}{2}'$  - 8', for c and s: 3' - 4') - types

## 1. poured concrete walls (thickness: 8" - 12")

a. wall forms with bracing

b. frames

1) pipes - gas, sewer, water, and electricity

2) windows (b)

3) ventilators (c)

- c. steel reinforcing - over windows (b) and ventilators (c)
  - d. concrete
  - e. anchor bolts - 8' o.c.
  - f. damp-proofing - cold or hot tar or asphalt (b,c)
  - g. rigid insulation - including damp-proofing (s)
  - h. termite protection
  - i. windows (b) or ventilators (c)
2. concrete block walls (thickness: 8", 10", 12")
- a. concrete blocks
  - b. solid cap blocks
  - c. mortar
  - d. frames - types
    - 1) pipes - gas, sewer, water, and electricity
    - 2) windows (b)
    - 3) ventilators (c)
  - e. anchor bolts - 8' o.c.
  - f. damp-proofing (b,c)
    - 1) cement-mortar coating
    - 2) hot or cold tar or asphalt
  - g. rigid insulation - including damp-proofing (s)
  - h. termite protection
  - i. windows (b) or ventilators (c)

#### D. flooring

- 1. preliminary installation of services - under slab (s)
  - a. included with electricity

- b. included with plumbing
  - 1) gas
  - 2) sewer
  - 3) water
- 2. base material (thickness: 4" - 6") - types
  - a. cinders
  - b. gravel
  - c. crushed rock
- 3. vapor barrier over base material - types
  - a. heavy plastic film
  - b. roll roofing
- 4. rigid insulation (s)
- 5. concrete slab (b,s) (thickness: 4" - 6")
  - a. reinforcing mesh
  - b. floor drains (b)
  - c. concrete
  - d. slab finish - types
    - 1) floated with wood or metal floats
    - 2) steel troweled
- 6. finish flooring (b,s) - types
  - a. wood-strip
    - 1) wood sleepers (adhesive)
    - 2) finish flooring (nail)
  - b. wood-block (adhesive)
  - c. asphalt tile (adhesive)

- d. vinyl-asbestos tile (adhesive)
- e. ceramic tile (adhesive and grout)
- f. slate (adhesive and grout)
- g. quarry tile (adhesive and grout)
- h. seamless (liquid applied)
- i. paint or seal concrete

E. foundation drainage (b,c)

1. materials around foundation

a. base and covering materials - types

- 1) cinders
- 2) gravel
- 3) crushed rock

b. draintile - types

- 1) concrete
- 2) clay

c. asphalt felt strips

2. sump

III. Suspended floor (unnecessary for slab foundation)

A. framing

1. posts - types

- a. wood (minimum: 6" x 6")
- b. steel filled with cement (minimum: 3½" diameter)

2. beams - types

- a. wood - built-up or solid

- b. steel - I-beam or wide flange
- 3. sill plate
  - a. sill sealer
  - b. wood sill plate (2" x 4" or 4" x 6")
- 4. joists - wood (2" x 8", 2" x 10", or 2" x 12")
  - a. header
  - b. stringer - 16" o.c.
- 5. subfloor - types
  - a. tongued-and-grooved boards (minimum thickness: 3/4", maximum width: 8")
  - b. square-edge boards (minimum thickness: 3/4", maximum width: 8")
  - c. plywood (thickness: 1/2" - 3/4")
- B. framing around openings - joists (stringers and headers) should be doubled - included with stairs or chimneys in miscellaneous
- C. preliminary installation of services under floor
  - 1. included with electricity
  - 2. included with plumbing
    - a. gas
    - b. sewer
    - c. water
- D. finish flooring - types
  - 1. wood-strip
    - a. building paper or felt - unnecessary over plywood subfloor
    - b. finish flooring (nail)

2. wood-block (adhesive or nail)
3. particleboard tile (adhesive)
4. resilient floors
  - a. underlayment - types
    - 1) plywood
    - 2) particleboard
    - 3) hardboard
  - b. finish flooring (adhesive) - types
    - 1) linoleum
    - 2) asphalt tile
    - 3) vinyl tile
    - 4) vinyl-asbestos tile
    - 5) rubber tile or sheet
5. seamless - requires plywood subfloor (liquid applied)
6. carpet (nail)
7. ceramic tile, slate, quarry tile
  - a. waterproof sealer
  - b. finish flooring (adhesive and grout)

#### IV. Exterior walls

##### A. wood framing - types

1. platform (same for each story)
  - a. vertical studs - 16" o.c. (2" x 4") - three studs required at each corner
  - b. sole plate (2" x 4") - sill sealer attaches it to foundation if it is just a slab

- c. doubled top plate (2" x 4")
  - d. let-in corner braces (1" x 4")
  - 2. balloon (studs extend from sill of the first floor to the top plate of the second floor)
    - a. vertical studs - 16" o.c. (2" x 4")
    - b. doubled top plate (2" x 4")
    - c. let-in corner braces (1" x 4")
    - d. firestops (2" x 4")
- B. wall sheathing - types
- 1. wood boards - sheathing paper (15 pound asphalt felt with 4" lap) required (minimum thickness: 3/4", width: 6" - 12") - types
    - a. horizontal
    - b. diagonal - corner braces unnecessary
  - 2. plywood - vertical - corner braces unnecessary (minimum thickness: 5/16", 4' x 8' or 4' x 9' sheets)
  - 3. structural insulating board - including insulation and vapor barrier - vertical - corner braces unnecessary (density: 15 - 31 pcf, 4' x 8' sheets)
  - 4. gypsum - horizontal (thickness: 1/2", 2' x 8' sheets)
- C. thermal insulation - used in all outside walls - types
- 1. flexible
    - a. blanket - including vapor barrier (thickness: 1 1/2", 2", or 3")
    - b. batt - vapor barrier optional (thickness: 4")
  - 2. rigid - same as structural insulating board (sheathing)
- D. vapor barrier - used on warm side of outside walls if it is not included with insulation - types
- 1. asphalt laminated paper

2. aluminum foil

3. plastic film

E. exterior doors and windows

1. framing around openings

a. header (two 2" members, width: 6" - 12")

b. double vertical studs at sides (2" x 4")

c. sill (window only) (2" x 4")

2. flashing across header

3. felt paper behind exterior casing (15 pound)

4. windows, frames, and glass as unit - including sash fitted and weatherstripped, frame assembled, exterior casing in place, and glass; storms and screens optional

a. window type

1) double-hung

2) casement

3) awning

4) horizontal sliding

5) stationary

b. frame type

1) wood

2) aluminum

3) steel

c. glass type

1) standard

2) insulated

5. exterior doors and frames

- a. frames - assembled with exterior casing
  - b. door (thickness: 1 3/4", minimum height: 6'8", width: 2'8" - 3') - types
    - 1) panel - wood - storms and screens optional
    - 2) flush - wood - storms and screens optional
    - 3) combination storm and screen - types
      - a) wood
      - b) metal
  - c. weatherstripping
  - 6. interior casings - for exterior doors and windows
  - 7. hardware - for exterior doors and windows
- F. exterior wall finish
- 1. wood siding - corner boards or metal corners required - types
    - a. horizontal - types
      - 1) bevel
      - 2) Dolly Varden
      - 3) drop - tongued-and-grooved
    - b. horizontal or vertical - paneling
    - c. vertical - sheathing paper (15 pound asphalt felt with 4" lap) required - types
      - 1) board and batten
      - 2) batten and board
      - 3) board and board
    - d. sheet materials - vertical - calked and battened at joints unless shiplap or matched edges used with flashing - types
      - 1) exterior grade plywood

- 2) paper-overlaid plywood
- 3) exterior grade particleboard
- 2. wood shingles - corner shingles required
- 3. asbestos-cement siding or shingles - corner shingles required
- 4. aluminum siding - metal corners required
- 5. masonry veneer
  - a. 5" offset on foundation
  - b. base flashing
  - c. sheathing paper (15 pound asphalt felt with 4" lap)
  - d. wall ties
  - e. mortar
  - f. bricks
- G. interior wall finish - see section on interior walls

#### V. Interior walls (partitions)

- A. wood framing
  - 1. vertical studs - 16" o.c. (2" x 4") - extra stud required at junction of interior and exterior walls
  - 2. sole plate (2" x 4")
  - 3. doubled top plate (2" x 4")
- B. interior doors
  - 1. framing around openings
    - a. header (two 2" members, width: 6" - 12")
    - b. double vertical studs at sides - only if load-bearing wall (2" x 4")
  - 2. interior doors and frames - including frame, door,

casing, and hardware and door fitted and prehung (thickness: 1 3/8", height: 6½' or 6'8", minimum width: 2'4") - types

- a. panel - wood
- b. flush - wood
- c. louvered - wood

C. interior wall finish

1. lath nailers

2. types of finish

a. lath and plaster finish

1) base materials - lath - types

- a) gypsum
- b) insulating fiberboard
- c) metal - used in bath and kitchen

2) corner beads - used for exterior corners

3) cornerites - used for inside corners

4) plaster finish

b. drywall finish - types

1) gypsum board (nail) - cement, tape, and cement at seams

2) plywood (nail or adhesive)

3) hardboard (nail)

4) fiberboard (nail)

5) wood paneling (nail)

c. ceramic tile

1) base material

2) waterproof sealer

## 3) finish tile (adhesive and grout)

## D. interior trim (excluding doors and windows)

1. base molding
2. base shoe
3. ceiling molding

VI. Roof (flat roof - flat or slightly pitched roof where one member supports roof and ceiling; pitched roof - both ceiling joists and rafters (or trusses alone) required)

## A. ceiling and roof framing - types

## 1. flat roof - conventional

- a. roof or ceiling joists - 16" o.c. (minimum: 2" x 6")
- b. lookout rafters - 16" o.c. (minimum: 2" x 6")

## 2. flat roof - post and beam

- a. posts
- b. beams
- c. metal angles
- d. decking material

1) plank roof decking - tongued-and-grooved solid wood - including structural support, sheathing, and ceiling finish - for beam spans up to 10' (2" x 6", 3" x 6", or 4" x 6")

2) fiberboard roof decking - tongued-and-grooved - including structural support and sheathing - for beam spans up to 4' (minimum thickness: 1½", 2' x 8' sheets)

## 3. pitched roof - not prefabricated - types

## a. gable roof

- 1) ceiling joists - 16" o.c. (minimum: 2" x 6")

- 2) rafters - 16" o.c. (minimum: 2" x 6")
- 3) ridge board (minimum: 1" x 8")
- 4) collar beams (minimum: 1" x 6")
- 5) end studs - 16" o.c. (2" x 4")
- 6) valleys
  - a) doubled valley rafter (minimum: 2" x 8")
  - b) jack rafters - 16" o.c. (minimum: 2" x 6")
- 7) dormers
  - a) side studs (2" x 4")
  - b) valley rafters (minimum: 2" x 6")
  - c) doubled rafters (minimum: 2" x 6")
  - d) header (minimum: 2" x 6")
  - e) jack rafters (minimum : 2" x 6")

b. hip roof

- 1) ceiling joists - 16" o.c. (minimum: 2" x 6")
- 2) rafters - 16" o.c. (minimum: 2" x 6")
- 3) ridge board (minimum: 1" x 8")
- 4) collar beams (minimum: 1" x 6")
- 5) hip rafters - 16" o.c. (minimum: 2" x 6")
- 6) jack rafters - 16" o.c. (minimum: 2" x 6")
- 7) valleys
  - a) doubled valley rafter (minimum: 2" x 8")
  - b) jack rafters - 16" o.c. (minimum: 2" x 6")

4. pitched roof - prefabricated trusses

- a. types of trusses - 2' o.c. (length: 20' - 32')

- 1) W-type
  - 2) King-post
  - 3) scissors
- b. erection - metal connectors required
- B. roof sheathing - for all roof types except post and beam - types
1. board (minimum thickness: 3/4", maximum width: 6" - 8") - types
    - a. closed
    - b. spaced - for wood shingle finish roofing only
  2. plywood (minimum thickness: 5/16", 2' x 8" to 4' x 9' sheets)
- C. thermal insulation
1. types for all roof types except post and beam - used in exposed ceilings
    - a. flexible
      - 1) blanket - including vapor barrier (thickness: 1 1/2", 2", or 3")
      - 2) batt - vapor barrier optional (thickness: 4" or 6")
    - b. loose fill
  2. type for all roof types - used in exposed ceilings or above decking in post and beam roof - rigid insulation - including vapor barrier (thickness: 1/2" to 3", 2' x 4' sheets)
- D. vapor barrier - used under insulation which does not include vapor barrier - types
1. asphalt laminated paper
  2. aluminum foil
  3. plastic film

## E. roof trim

## 1. cornices - types

- a. box
- b. close
- c. open - only used with plank roof decking on a post and beam roof

## 2. end trim - gable roof only

- a. cornice return
- b. gable-end finish
  - 1) wide rake
  - 2) close rake

## F. sheet metal

## 1. types of metal

- a. galvanized metal
- b. terneplate
- c. aluminum
- d. copper
- e. stainless steel

## 2. flashing on roof

- a. flashing only for gravel finish on flat roof - gravel stop
- b. flashing only on pitched roof
  - 1) ridge
  - 2) valley
  - 3) shingle
- c. flashing on all roof types

1) metal edging

2) flashing collars

a) vent

b) chimney - included with chimney in  
miscellaneous

3. gutters and downspouts - types

a. metal

b. wood

G. exterior roof finish

1. types for flat roof

a. built-up finish

1) felt

2) tar or asphalt

3) gravel or cap sheet of roll roofing

b. plastic film - backed with asbestos sheet

2. types for pitched roof

a. wood shingles

1) roof underlay (15 pound asphalt felt)

2) nailing strips

3) finish roofing

b. other finishes

1) roof underlay (15 pound asphalt felt)

2) finish roofing - types

a) asphalt shingles

b) asbestos shingles

c) slate

d) tile

H. ceiling finish - unnecessary for plank roof decking on a post and beam roof

1. lath nailers

2. types of finish

a. lath and plaster finish

1) base material - lath - types

a) gypsum

b) insulating fiberboard

c) metal - used in bath and kitchen

2) cornerites - used for inside corners

3) plaster finish

b. drywall finish - types

1) gypsum board (nail) - cement, tape, and cement at seams

2) plywood (nail or adhesive)

3) hardboard (nail)

4) fiberboard (nail)

5) wood paneling (nail)

6) acoustical tile (nail)

## VII. Heating and ventilation

A. heating system - types

1. forced hot air

a. furnace-fueled by electricity, gas, or oil

b. blower

- c. ducts
- d. registers
- 2. hot water
  - a. furnace - fueled by electricity, gas, or oil
  - b. circulator
  - c. piping
  - d. radiators
- 3. hot steam
  - a. furnace (boiler) - fueled by electricity, gas, or oil
  - b. piping
  - c. radiators
- 4. electrical
  - a. wiring from panel board
  - b. baseboard radiation units
- 5. radiant
  - a. furnace - fueled by electricity, gas, or oil
  - b. piping
  - c. floor coils or baseboard units
- B. special ventilation
  - 1. attic - vents
  - 2. kitchen
    - a. fan with grease filter or hood
    - b. duct
  - 3. bathroom
    - a. fan

b. duct

### VIII. Electricity

#### A. electric service into house

1. bring cable into house (minimum: 100 amp)
2. watt-hour meter
3. house main power switch (service disconnect)
4. panelboard - containing fuse or circuit breaker box

#### B. wiring

1. lighting circuits - for lights, switches, and plugs  
(one circuit for every 500 square feet of house (20 amp))
2. special purpose circuits - for range, refrigerator, disposal and dishwasher, furnace, hot water heater, and washer and dryer (20 - 50 amp)

#### C. socket outlets - sealed with vapor barrier if on exterior wall

1. plug assemblies (one every 12 feet of room wall)
2. switch assemblies (at least one per room)

#### D. light fixtures

#### E. telephone

1. wiring
2. phone

### IX. Plumbing

#### A. gas

1. gas into house
  - a. house gas pipe with shutoff valve
  - b. gas meter

2. piping for systems using gas

a. systems possibly using gas - range, refrigerator, furnace, hot water heater, and dryer

b. materials for piping - types

1) wrought iron

2) steel

3) cast iron (piping over 4" in diameter)

4) brass (piping over 4" in diameter)

5) copper (piping over 4" in diameter)

B. waste and water

1. sewer into house

a. house sewer pipe

b. house drain pipe

1) trap

2) vent

3) cleanout

2. water into house

a. house water pipe

b. water meter

3. hot water heater

a. storage - heat with steam, hot water, gas, or electricity

b. instantaneous - heat with steam or hot water

4. plumbing fixtures and accessories - fixtures include 10' of each of three types of piping, fittings for each, and the trap and its fittings

a. necessities for each fixture

- 1) soil or waste stack piping and fittings
- 2) trap and fittings
- 3) vent piping and fittings
- 4) water supply piping and fittings

b. materials for piping and fittings - types

- 1) cast iron
- 2) copper
- 3) steel
- 4) brass
- 5) wrought iron
- 6) lead

c. fixtures

- 1) utility sink
- 2) kitchen sink - types
  - a) stainless
  - b) porcelain
- 3) lavatory
- 4) water closet
- 5) bathtub - types
  - a) enamel iron
  - b) fiberglass
- 6) shower - types
  - a) enamel iron
  - b) fiberglass

5. indirect waste piping for appliances (same materials as used for fixture piping above)

- a. washer
- b. dishwasher
- c. refrigerator

## X. Appliances

- A. stove (range and oven, possibly hood) - types
  - 1. electrical
  - 2. gas
- B. refrigerator - types
  - 1. electrical
  - 2. gas
- C. disposal
- D. dishwasher

## XI. Painting and finishing

- A. exterior wood finishing - types
  - 1. prefinished
  - 2. natural finish - types
    - a. no finish - just weathered
    - b. water-repellent preservative without pigment  
(finish every year for 2 or 3 years, then less often)
    - c. water-repellent preservative with pigment (finish every year for 2 or 3 years, then less often)
    - d. pigmented penetrating stain (first coat lasts 2 to 4 years, other coats after that last for 8 to 10 years; or, initially apply 2 coats and it lasts for 10 years, then 1 coat every 10 years)
  - 3. opaque paint finish - steps for painting exterior

- a. water-repellent preservative treatment
  - b. 1 primer coat - nonporous linseed oil primer
  - c. 2 finish coats - types
    - 1) latex
    - 2) alkyd
    - 3) oil-base
  - d. repaint when necessary
- B. interior wall, ceiling, door, cabinet, stair, and trim finishing - types
- 1. opaque paint finish - types
    - a. paint as exterior is painted
    - b. steps for painting interior
      - 1) fill large pores in any wood with wood filler
      - 2) 1 primer coat - nonporous linseed oil primer
      - 3) 1 - 2 undercoats - types
        - a) enamel
        - b) semigloss enamel
        - c) latex
      - 4) 1 finish coat - types
        - a) enamel
        - b) semigloss enamel
        - c) latex
  - 2. transparent finish (wood paneling, doors, cabinets, and trim only)
    - a. fill large pores with wood filler
    - b. finish - types

- 1) pigment water stains
- 2) pigment oil stains
- 3) finish without pigment
  - a) sealer coat - thinned out varnish
  - b) surface coat - types
    - i) gloss varnish
    - ii) semigloss varnish
    - iii) nitrocellulose lacquer
    - iv) wax
3. wallpaper (walls only)
  - a. 1 - 2 undercoats of paint
  - b. wallpaper (glue)
  - c. sealer
4. prefinished (wood paneling, doors, cabinets, and trim only)
- C. interior wood floor and stair finishing -- may include base molding and shoe - types
  1. prefinished
  2. stain finishing
    - a. sanding
    - b. filler if necessary - paste or liquid, natural or colored
    - c. stain - oil-base or non-grain-raising at least
    - d. finish - types
      - 1) sealer - thinned out varnish
      - 2) varnish

e. wax - over finish - types

- 1) paste wax (2 coats)
- 2) liquid wax (2 or more coats)

XII. Miscellaneous

A. cabinets (kitchen and bathroom)

1. types

- a. base (height: 30" - 38", depth: 15" - 30")
- b. wall (height: 12", 15", 18", or 24", depth: 4" - 18")

2. cabinet material - types

- a. wood
- b. metal

3. countertops over base cabinets - types of materials

- a. formica
- b. plastic
- c. ceramic tile

B. closets - types

1. clothes

- a. wood shelf
- b. rod - types
  - 1) wood
  - 2) metal
- c. door and frame - including frame, door, casing, and hardware and door fitted and prehung - types
  - 1) panel - wood
  - 2) flush - wood

3) louvered - wood

2. linen

a. wood shelves

b. door and frame - including frame, door casing,  
and hardware and door fitted and prehung - types

1) panel - wood

2) flush - wood

3) louvered - wood

C. bathroom accessories

1. mirror - types

a. wall hung plain

b. wall hung with medicine chest

2. towel racks

3. soap dishes

4. shower curtain bar or door

D. stairs

1. types - by design

a. straight run

b. long L - including middle landing

c. narrow U - including middle landing

d. winders

2. general construction

a. framing opening in floor - two ways

1) long dimension parallel to joists (best way)

a) 2 double headers

b) 2 double trimmer joists

c) tail joists - 16" o.c.

2) long dimension perpendicular to joists

a) double header

b) beam (if no wall)

c) 2 double trimmers

d) tail joists - 16" o.c.

b. landings (minimum length:  $2\frac{1}{2}'$ ) - types

1) top of stairs - required if door opens into stairway

2) middle of stairs - post necessary if no wall

3. types - by use

a. basement (minimum clear width:  $2\frac{1}{2}'$ , minimum height clearance: 6'4")

1) 2 or 3 notched or un-notched stair carriages (2" x 12" planks)

2) 2 firestops

3) treads (minimum width: 9")

4) risers - optional (maximum height:  $8\frac{1}{4}"$ )

5) handrail - at least one if there are more than 3 risers - open stairway requires two

b. main (minimum clear width: 2'8", minimum height clearance: 6'8")

1) 2 housed stringers (notched carriage if necessary)

2) hardwood wedges

3) 2 firestops

4) routed and grooved treads (minimum width: 9")

- 5) routed and grooved risers (maximum height: 8 $\frac{1}{4}$ "
- 6) handrail - at least one if there are more than 3 risers - open stairway requires two
- 7) balusters and newel post - used with railing if stairs open on one side

#### E. chimney - types

##### 1. lightweight prefabricated chimney (no fireplace)

a. framing opening in floor, ceiling, or roof (clearance for rafters, joists, or headers: 2", clearance for sheathing or subfloor: 3/4")

- 1) 2 double headers
- 2) 2 double trimmer joists or rafters
- 3) tail joists or jack rafters
- 4) firestops - required between chimney and frame members

b. no concrete footing required

c. no masonry protection required

d. metal flashing

##### 2. standard chimney (no fireplace)

a. framing opening in floor, ceiling, or roof - see section for lightweight chimney

b. concrete footing

c. chimney construction

- 1) flue lining
- 2) masonry (minimum of 4" about each flue)
- 3) concrete cap

d. metal flashing

## Appendix B

## PARTIAL LIST OF OPTIONS

The following partial list of options includes what, to the author, seem to be most of the sets of options, available to the designer or builder, which might make a difference in the construction cost of housing. The list was taken from the outline in Appendix A. It is worthy of notice that the sets of options within each phase cannot be considered to be independent of one another (e.g. floor finish (2.2) depends upon the type of foundation (2.0)) even though the phases of construction usually can be.

Unless it is indicated otherwise (e.g. site development is an exception to the general rule), the model user will have to choose at least one option from each of the sets of options (major subdivisions) within each phase of construction. By choosing more than one option in at least some of the sets, he will be able to see the effects that alternatives in construction can have on the initial development cost.

It should be noted that many of the sets of options have a group of options, called "user specified combinations of above options", at the end of their sets. Such an option is one in which the model user can specify a combination of options within the set to make up a single option (e.g. in the set, type of foundation, one might want to consider the house built over a foundation which is half basement and half crawl space - this would make up a single option). These

options are not to be confused with the alternatives in construction discussed in the previous paragraph (e.g. one might want to consider a house built over a basement or one built over a slab - this would make up two options).

1. Site development\* (one condition must be chosen from each category to make up one option)

- |            |   |  |
|------------|---|--|
| category 1 | } | 1.0 soil conditions under house                  |
|            |   | 1.00 medium sand and gravel                      |
|            |   | 1.01 light clay                                  |
|            |   | 1.02 heavy clay                                  |
|            |   | 1.03 hardpan                                     |
|            |   | 1.09   |
| category 2 | } | 1.1 site conditions under house - natural growth |
|            |   | 1.10 clear                                       |
|            |   | 1.11 densely wooded                              |
|            |   | 1.12 lightly wooded                              |
|            |   | 1.13 brush and scrub                             |
|            |   | 1.19   |
|            |   | 1.2 site conditions under house - structures     |
|            |   | 1.20 clear                                       |
|            |   | 1.21 paving                                      |
|            |   | 1.22 concrete foundation                         |
|            |   | 1.23 block foundation                            |
|            |   | 1.24 small masonry building                      |
|            |   | 1.25 small wooden building                       |
|            |   | 1.29   |

---

\* note: Model user must input land acquisition and soil testing costs with each option.

## 2. Foundation

### 2.0 type of foundation

2.00 basement

2.01 crawl space

2.02 slab

2.03 } user specified combinations of above options  
 : } (e.g. house rests on  $\frac{1}{2}$  basement and  $\frac{1}{2}$  crawl space)  
 : }  
 2.09 }

### 2.1 foundation material

2.10 poured concrete - standard

2.11 poured concrete - hi early

2.12 concrete block

:

2.19

### 2.2 floor finish

2.200 none

2.201 natural

2.202 paint

2.203 seamless

2.204 asphalt tile

2.205 vinyl-asbestos tile

2.206 wood-block

2.207 wood-strip

:

2.290 } user specified combinations of above options  
 : }  
 2.299 }

### 3. Suspended floor

#### 3.0 floor finish

3.000 wood-strip

3.001 wood-block

3.002 particleboard tile

3.003 linoleum

3.004 asphalt tile

3.005 vinyl tile

3.006 vinyl-asbestos tile

⋮

3.090 } user specified combinations of above options  
 ⋮ }  
 3.099 }

### 4. Exterior walls

#### 4.0 windows - number, size, type, location

4.000 double-hung

4.001 casement

4.002 awning

4.003 horizontal sliding

4.004 stationary

⋮

4.090 } user specified combinations of above options  
 ⋮ } giving number, size, and location of each  
 4.099 }

#### 4.1 exterior wall finish

4.100 horizontal redwood siding

4.101 horizontal cedar siding

4.102 vertical redwood siding

- 4.103 aluminum siding
- 4.104 plywood siding
- 4.105 wood shingles
- 4.106 asbestos-cement shingles
- 4.107 brick veneer
- ⋮
- 4.190 } user specified combinations of above options
- ⋮
- 4.199 }

## 5. Interior walls

### 5.0 interior wall finish

- 5.000 plaster
- 5.001 gypsum board
- 5.002 plywood
- 5.003 wood paneling
- 5.004 ceramic tile
- ⋮
- 5.090 } user specified combinations of above options
- ⋮
- 5.099 }

## 6. Roof

### 6.0 type of roof

- 6.00 conventional flat roof
- 6.01 post and beam flat roof
- 6.02 gable roof
- 6.03 hip roof

6.04 prefabricated roof truss

⋮

6.09

6.1 exterior roof finish

6.10 built-up

6.11 plastic film

6.12 wood shingles

6.13 asphalt shingles

6.14 asbestos shingles

⋮

6.19

6.2 ceiling finish

6.200 none

6.201 plaster

6.202 gypsum board

6.203 plywood

6.204 wood paneling

6.205 acoustical tile

⋮

6.290

⋮

6.299

} user specified combinations of above options

7. Heating and ventilation

7.0 type of heating

7.00 forced hot air

7.01 hot water

7.02 electrical

7.03 radiant

7.04 hot steam

⋮

7.09

8. Electricity (no options)

9. Plumbing

9.0 gas

9.00 yes

9.01 no

9.1 plumbing fixtures - number, type

9.100 utility sink

9.101 kitchen sink

9.102 lavatory

9.103 water closet

9.104 bathtub - enamel

9.105 bathtub - fiberglass

9.106 shower

⋮

9.190 } user specified combinations of above options  
 ⋮ } giving number of each  
 9.199 }

10. Appliances (no options)

11. Painting and finishing

11.0 exterior wood finishing

11.000 none

11.001 prefinished

11.002 water-repellent preservative without pigment

11.003 pigmented penetrating stain

11.004 latex paint

11.005 alkyd paint

⋮

11.090

⋮

11.099

} user specified combinations of above options

11.1 interior wall, ceiling, door, cabinet, stair, and trim finishing

11.100 prefinished

11.101 enamel

11.102 semigloss enamel

11.103 pigment water stains

11.104 gloss varnish

11.105 wallpaper

⋮

11.190

⋮

11.199

} user specified combinations of above options

11.2 interior wood floor and stair finishing

11.20 prefinished

11.21 oil-base stain and varnish

⋮

11.25

⋮

11.29

} user specified combinations of above options

## 12. Miscellaneous

12.0 stairs

12.00 none

12.01 main stairs

12.02 basement stairs

12.03 main and basement stairs

⋮

12.09

12.1 chimney

12.10 prefabricated chimney

12.11 conventional chimney

⋮

12.19

## Appendix C

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