COST REDUCTION THROUGH PREFABRICATION: A DESIGN APPROACH

Avi Friedman and Vince Cammalleri

Abstract

The Grow Home is a 93-square-meter rowhouse, 4.3 meters wide, developed by the Affordable Homes Program at McGill University in response to the affordable housing challenge. The kitchen, bathroom, and living room are located on the ground floor, and an unpartitioned second floor is proposed in an effort to reduce costs and enable the owners to complete the unit at their own discretion. This paper examines how the Grow Home can be adapted to an industrialized method of production, using prefabricated panel systems, and determines the implications such construction would have in terms of quality, economy, and technical performance. The research includes an adaptation to the unit's design and a cost estimate comparing prefabricated systems with conventional construction methods.

A framework for the industrialization of the Grow Home was developed by adapting the unit's design to provide sufficient flexibility for the builder and economies of scale for the manufacturer. Architectural, modular, and technical design criteria were established based on feedback from manufacturers, builders, and occupants of existing Grow Home projects. A wide range of options for the dwelling's layout was generated using a small number of simple, standard components. Nine panel configurations were proposed in all, six for the front and back elevations and three for the side walls of the end units. The use of small, standard interior partitions provided various configurations for entrances and bathrooms, while enabling on-site changes to be made fairly easily in response to a client's request.

The potential for prefabricated systems to reduce construction costs was addressed by examining the costs of several prefabricated components, including exterior walls, floors, partitions and dividing walls. The analysis demonstrated that prefabricated panel systems can, for the most part, provide a competitive alternative to conventional construction. The magnitude of the savings, however, can vary significantly depending on the type of panel system, the degree of prefabrication, and the component in question. When the scope of prefabricated components was extended to include floors and partitions, savings up to 6% were found to be possible. For the construction of 30 or more units, this represents savings of up to $95,000 ($3,150 per unit).

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During the writing of this article, Vince Cammalleri was a research associate to Professor Friedman.

Introduction

Researchers in the field of prefabrication often maintain that the industrialization of housing holds many advantages over conventional construction methods (Robinson, 1988; Kjeldsen, 1988). The assembly of units, panels, or components under factory-controlled conditions, they argue, yields a higher quality product, and generally results in more energy-efficient homes as well, because of the optimum conditions under which the insulation is installed. Due to quick and efficient on-site assembly, the effect of poor weather conditions, particularly in cold climates, is reduced, as is the potential for damage from inadequate material storage and vandalism. Clean-up time and material costs are reduced because less waste, construction management and trade coordination are simplified, and the need for large teams of skilled on-site labor for multiple-unit construction is substantially lowered. While the potential for cost reduction is significant, particularly for standard designs and high production volumes, many of these savings might be offset by delivery, installation, and inventory costs, as well as by higher fixed costs associated with keeping a plant under operation during the winter months when the demand is low, and during years of reduced construction activity.

Despite its many advantages, the use of prefabricated homes in Canada has been slow in gaining acceptance (although the use of prefabricated components – e.g., wall sections – is on the increase). In fact, sale of factory-built housing has decreased to about 7% in 1997 from its peak in 1974, when it accounted for 20% of total housing starts (CMHI, 1998; Baristow, 1985; Cooke, 1993). On the other hand, factory-built housing has been on the increase in countries such as Japan, the United States, and Sweden. In the United States, prefabricated housing accounts for 58% of housing starts, with 15% attributed to mobile homes and 37% to panelized construction; in Sweden, prefabricated housing accounts for almost 90% of housing starts (*Automated Builder*, 1992). The varied reasons for the relatively small percentage of factory-built homes in Canada remain a question for debate.

The type of unit, along with its layout, configuration, and size, will inevitably affect the cost in both conventional and prefabricated construction. It is conceivable that a design which is flexible, simple, efficient, and small could provide more savings in its prefabricated form than it would for more conventional types of construction. In light of this potential, the purpose of this paper is to examine the possibilities for prefabricating a specific design, and to provide guidance as to how it can be optimized to suit the manufacturing process and further reduce costs. The model used was the Grow Home – the product of a research effort aimed at addressing the problem of affordable housing in the urban context – which was successfully implemented in the Montreal area. The analysis addressed the builder's point of view, and was conducted in the context of the Canadian housing market.

The Grow Home and its Potential for Prefabrication

The Grow Home is a 93-square-meter rowhouse, 4.3 meters wide. It was developed by the Affordable Homes Program at McGill University in response to the affordable housing challenge (Rybczynski, Friedman, & Ross, 1990). The kitchen, bathroom, and living room in the Grow Home are located on the ground floor, and an unpartitioned second floor (which could eventually be finished to include two bedrooms and a second bathroom) is proposed in an effort to reduce costs and to enable the owners to complete the unit at their own discretion. A full-scale prototype, sponsored by Dow Canada, was erected on the McGill university campus and opened to the public for one month. Shortly after the demonstration unit was dismantled, several housing projects based on the Grow Home concept were started. Within five years, approximately 6,000 units were built in some 25 projects in the Montreal area, ranging in price from $69,000 to $95,000 (Friedman & Cammalleri, 1993; Friedman & Cammalleri, 1992). The Grow Home was found to be an extremely effective solution to the housing affordability challenge: a Grow Home with a cost of $76,000 could be financed by a person or household with an annual income of just over $23,000. Moreover, short shopping periods for purchasers of Grow Homes and quick decisions to buy (59.5% of buyers were not actively looking to buy at the time of purchase, and 61.3% looked no further after seeing their eventual home) suggest that the Grow Home projects filled a market void and represented a unique opportunity for most buyers, an exceptional bargain not to be passed up (Friedman, 1994).

The built projects revealed some interesting interpretations of the Grow Home concept (Figure 1). While the 4.3-meter width was retained in all cases, each of the builders modified the design to suit the tastes and budgets of his own particular market. The original plan, which subdivided the space with a central plumbing/stair core, was al-

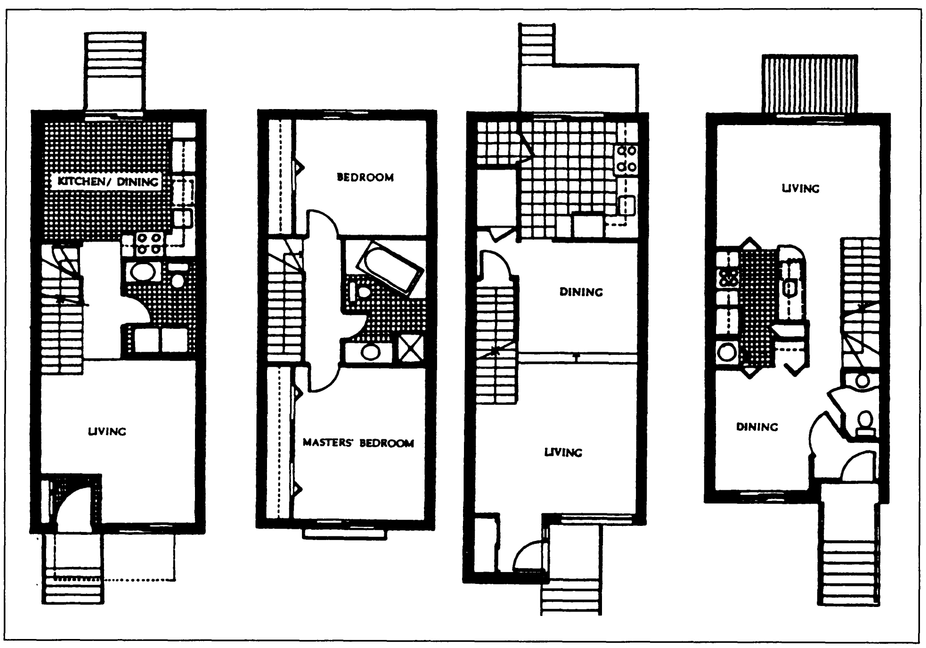

Figure 1. Built plan variations.

tered in most cases to accentuate the full depth of the space. The second floor was partitioned and finished in most of the projects, some with "luxurious" bathrooms having separate showers and whirlpool baths. Many of the builders provided brick veneer on the exterior to increase quality and project an image of permanence, while the remainder used a cement-based aggregate finish. All units were built with basements, which made it possible to add up to 46.5 square meters to the usable floor area, and indoor garages were included in about 15% of the homes. Vestibules and walk-in closets were added to the units in some of the projects, while separate garages were added to the sides in one other.

The small size, simple configuration, and efficient layout of the Grow Home provides an opportunity to exploit the advantages of prefabricated methods of building to their maximum potential. They tend to maximize the efficiency of building erection, making it appropriate for several levels of prefabrication. The 4.3-x-11 meter rectangle, for instance, lends itself to easy modular prefabrication and transportation. The simple exterior configuration and symmetry allow for quick, uncomplicated panelized construction and assembly. The Grow Home's technical design makes use of standard material dimensions, thereby minimizing the cutting and fitting operations as well as material wastage. This standardization facilitates the prefabrication of packaged assembly kits. By using prefabricated roof trusses of standard size and slope, the roof construction is also quick and efficient. Spanning front to back, these trusses eliminate the need for structural partitions on the upper floor and make that space flexible.

The built projects made extensive use of prefabricated components. In addition to the roof trusses, prefabricated door frames, window units, kitchen cabinets, railings, exterior concrete stairs and structural components (I-joists) were selected to simplify assembly and reduce construction time. The use of these components provides a starting point for the development of an industrialized version of the Grow Home, whereby other prefabricated systems and subsystems (walls, floors, roofs, foundations, etc.) would form part of a complete system package.

Design Adaptation

Methodology

The adaptation of the Grow Home for industrialization was carried out in three stages. In the first stage, a working model was selected. The model was based on four variations of the Grow Home concept that were built and sold in the Montreal area. The construction of the units had been monitored, their builders interviewed, and their occupants surveyed. In the second stage, a set of criteria was established to guide the design optimization process. Guidelines were drafted in three areas: architectural design, which responded to the occupant's expressed preferences and aspirations; modular standardization, which addressed the prefabrication process itself; and technical factors, which were aimed at improving the quality of the products by exploiting the strengths and eliminating the weaknesses of each type of panel system. Finally, the design of the model units was optimized to conform to the architectural, modular and technical design criteria. The process was carried out for six types of panel systems simultaneously. The number of options which could be generated for the interior layout using the four model plans was considered to be sufficient to provide selection and flexibility to meet the demands of a range of prospective buyers.

The design process was aimed at providing sufficient flexibility for the builder, and economies of scale for the manufacturer, by generating a wide range of options for the dwelling using a small number of simple, standard components. This flexibility would enable mass prefabrication of components without any need to finalize the design. Modifications to the interior layout could then be made on site simply by adding or replacing components. The design process evolved from the inside out, starting with a general, basic analysis of the overall modular dimensions of the dwelling, followed by more specific configurations of the interior plan, and ending with the exterior walls. This sequence was considered to be most suitable, since the flexibility and applicability of standard exterior prefabricated walls depends largely on the interior plan. Four aspects of the house were examined: general dimensions, stair configuration and orientation, interior partitions, and exterior walls. A CAD software was used as a design tool. Because the design process involved the manipulation of standard components within established modules, the use of a computer provided an efficient method of generating and testing alternatives.

General Dimensions

Four basic arrangements for the interior spaces were generated for the ground floor based on the starting plans described previously. These include units with a stair core (SC), an open core (OC), a bathroom core (BC) and a kitchen core (KC). For the basement and upper floors, the number of arrangements is limited by the types of rooms that are found at these levels. Only the first two options (SC, OC) apply to these plans (Figure 2).

At the ground floor, the larger module (A) is generally intended to accommodate either a living space or a combined kitchen/dining area. The smaller modules (B and C) are sufficient for dining rooms, kitchens, or bathrooms. At the upper level, all of the modules can be used to accommodate either a bedroom, a den, a play area or a bathroom. The design appears to be most efficient when the central module (C) is used for the bathroom, while the larger of the remaining two (A, B) is designated the master bedroom.

The manner in which the units were grouped, as well as their setting, affected the possible use of a space as well as the quality of light that it was likely to have. Depending on the context in which the units are built, there may be a preference for a particular orientation. Builders may prefer to have bathroom cores back-to-back on adjoining units, buyers may want south-facing kitchens, and the addition of a window to the side wall of an end unit may require that a reversed floor plan be used. Figure 3 shows four alternatives that could be generated by reversing the units either front to back, left to right, or both. Reversing the unit front to back, for example, will dictate whether the larger module will face the front or back of the house. At the upper level, this reversing will determine where the master bedroom is located. At the ground level, it makes it possible to enter the unit through either the kitchen or the living area.

Stair Configuration and Orientation

In a narrow and simple unit such as the Grow Home, many aspects of the interior layout will depend on the stair. The size, type, configuration, orientation, and location of the stair will affect everything from the size of the rooms to the general appearance and functional layout of the spaces. The ability of the builders to offer a variety of

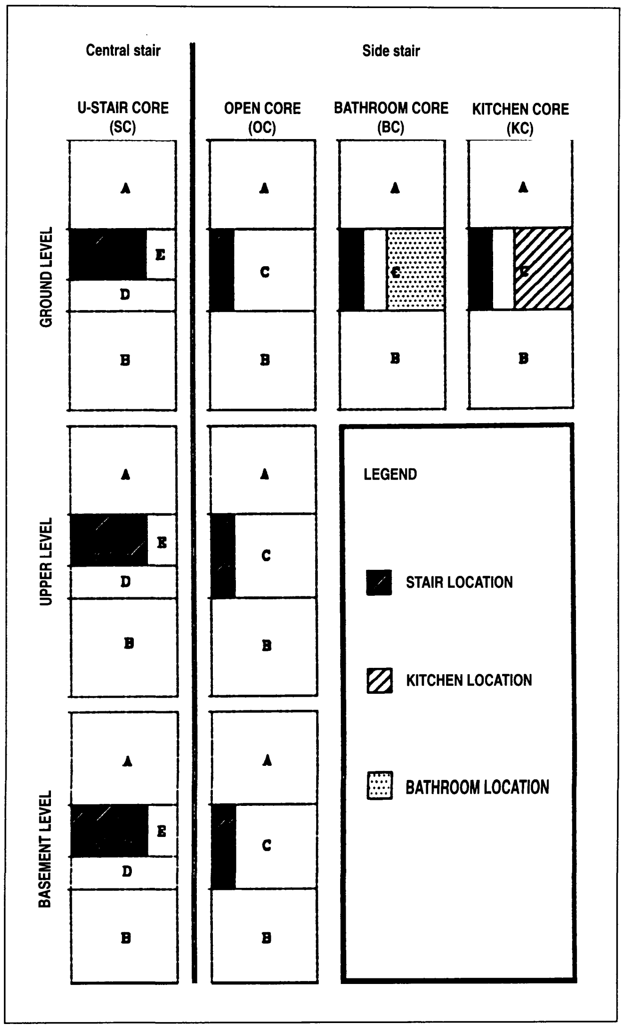

Figure 2. Segmentation of floor plans.

options and to make on-the-spot changes will therefore depend on the type of stair they have committed to. The construction of a staircase is usually more labor intensive than other framing tasks. Once built, it is not easily changed, particularly if the modification involves a different-sized opening in the floor. Prefabricating the stair would enable several options to be offered for the same standard opening in the floor, and on-site changes to the layout could be made by either reversing or replacing the stair modules. In light of this potential for increased flexibility and standardization of parts, the stair in the units was examined as an integral part of the prefabricated component system (in Canada, a standard riser/tread ratio of 7/11 is used, as specified in the National Building Code).

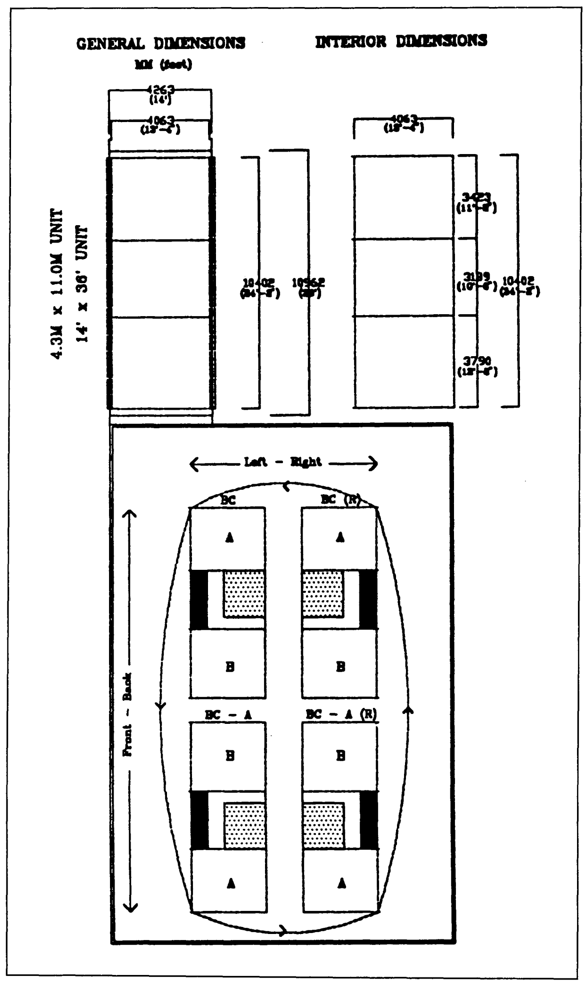

Figure 3. Reversed options.

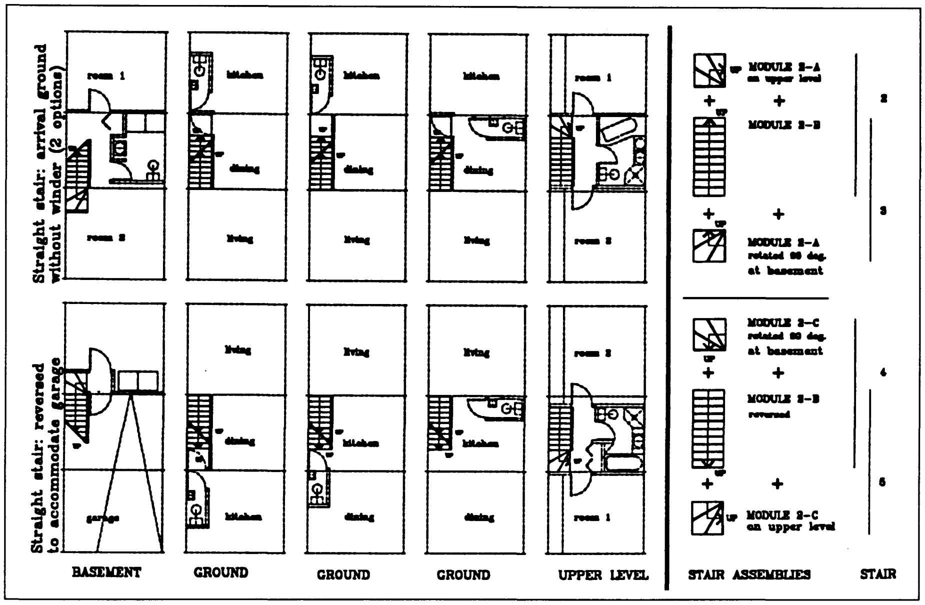

Figure 4. Effect of stairs on options for interior layout.

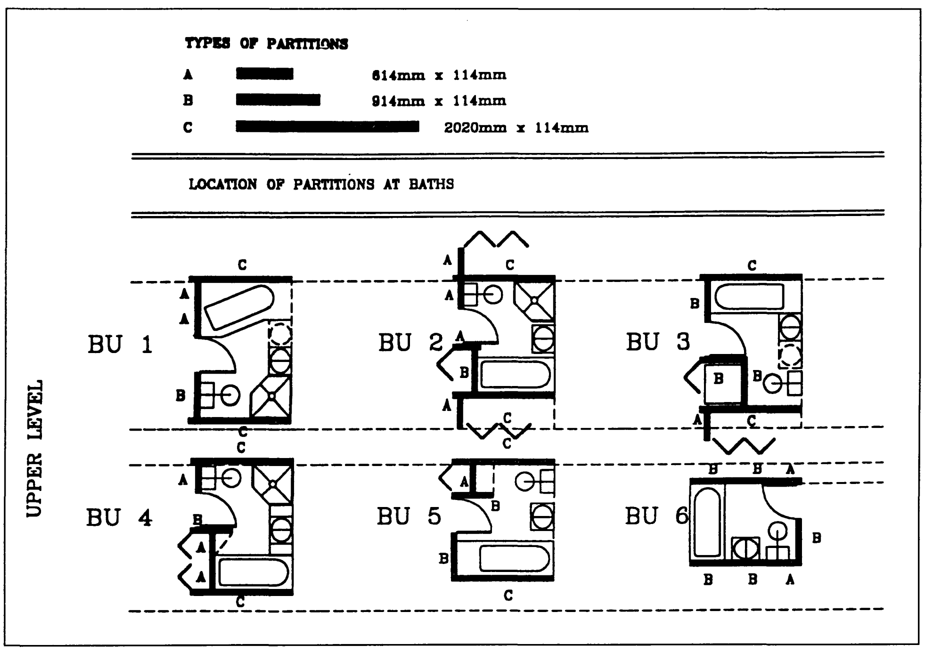

Figure 5. Optional bathroom configurations using standard paritions.

Some of the implications of the stair's configuration and orientation with respect to the interior layout of the units are illustrated in Figure 4. Although many other options are possible, these diagrams serve to illustrate how the stair affects the potential for space usage and, ultimately, the adaptability of the space. In general, the orientation of the stair (direction: up or down) will dictate whether or not the unit can accommodate a garage in the basement. The method of arrival (with winders or straight) will affect several aspects of the layout.

Interior Partitions

Interior partitions and finishes are also of interest in that they represent about 30% of construction costs. These costs could potentially be reduced by transferring them either to the buyer (by providing unfinished or partially finished units) or to the fabricator. The latter would require that the exterior wall panels be delivered as closed systems (with the gypsum wallboard installed) and/or that the interior partitions be economically prefabricated, delivered, and installed.

Several options were developed by the authors for the unit's bathrooms and entrances using three standard partitions: 614 mm, 914 mm, and 2020 mm. Although the assembly of small partitions in series may require more framing members than a continuous one, the increased flexibility, speed of assembly, and standardization may lead to economies of scale which might offset the added material costs. Figure 5 illustrates how 15 different bathroom configurations could be built for the basement, ground, and upper levels using the same standard partitions. The alternatives include options for large tubs, double sinks, separate showers, linen closets, and washer/dryer placement. Once the stairs, bathrooms and entrances have been standardized, a variety of possibilities for the interior layout of the dwelling can be generated by treating these as modules in themselves. Examples of how these diagrams translate into floor plans are given in Figure 6 for the ground floor.

Exterior Walls

The design of standard exterior wall panels was aimed at accommodating the range of options generated for the interior layout, while addressing the cost-saving recommendations put forth by the fabricators. The latter included the use of larger panels and simple, standard-sized openings located between the structural members of the wall system where possible. Nine panel configurations were proposed in all: six for the front and back elevations and three for the side walls of the end units. Rowhouse versions of the home could be built with anywhere from two to four panels, while semi-detached or end units would require three to six.

The biggest challenge in standardizing the exterior wall panels is keeping their number at a minimum while providing a pleasant and functional interior for each of the layouts generated. There are two basic ways of reducing the number of standard panels. The first is to design them so that they can be rotated to suit the layouts of both the fronts and backs, left or right sides of the same or different units. The second approach is somewhat more restrictive, and deals with making the panels reversible. In this case, panels can be shifted

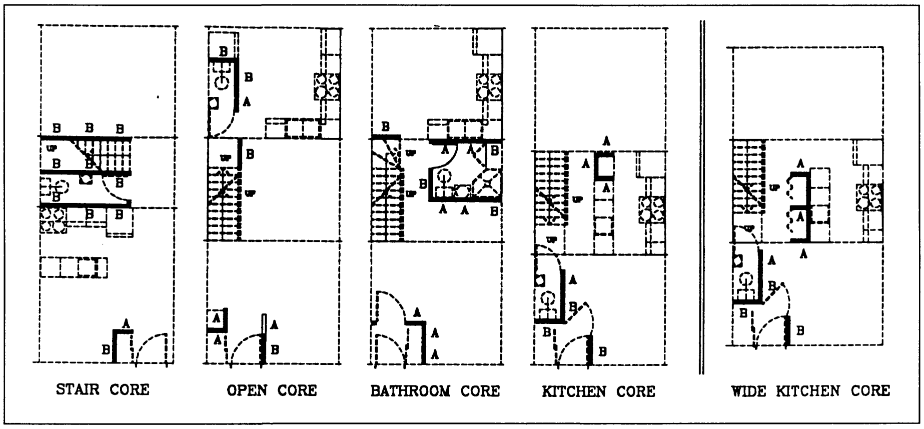

Figure 6. Location of partitions at ground.

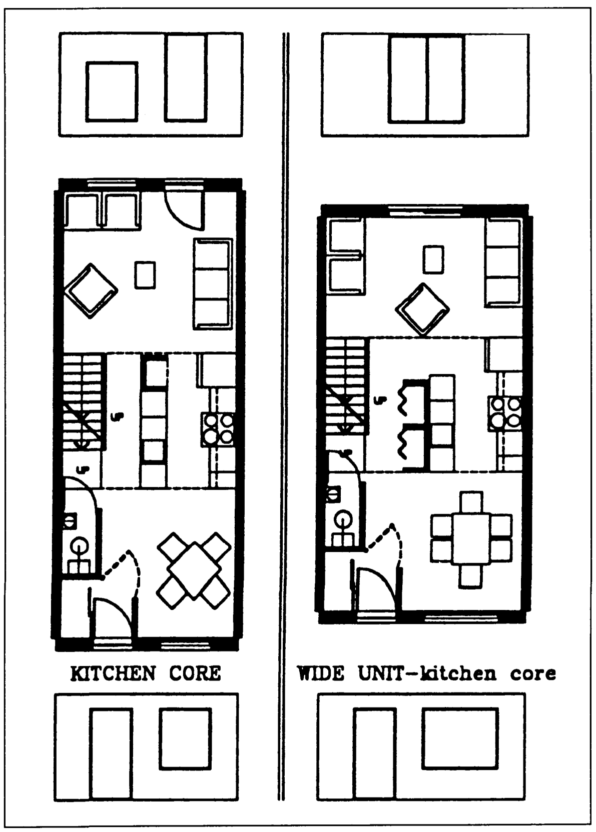

Figure 7. Sample ground level arrangements using standard components.

from front to back or from side to side without the need to change their orientation. Such shifting would require that the panel be symmetrical about its cross-section, a quality which is characteristic only of structural sandwich panels. Unsheathed structural panels could not be reversed, since they are either equipped with pre-cut electrical chases or designed with an air space to accommodate electrical wiring, either of which gives the panels a definite interior and exterior side. Figure 7 illustrates some of the plan options that could be assembled using various modules for entrance, bathroom, and stair. The number of partitions and panels required for a particular design are shown in Figure 8.

Cost Analysis

Costs for both conventional construction and prefabricated panel systems were estimated in order to determine whether significant savings could be achieved with prefabrication using adapted versions of the Grow Home. The possibility of integrating other prefabricated components available from the panel manufacturers was also investigated, as were transportation costs.

One of the plan options was selected as a basis for acquiring cost estimates. It was assumed that individual cost estimates for each of the plans developed would not be necessary, since there is no significant difference between the designs that would affect the comparison. The unit chosen was the open-core model with the kitchen in the back. Variations of this model account for some 80% of the units sold in the Montreal area, and continue to be the most popular options for builders. The plan was distributed to five panel manufacturers for cost estimates of their systems, and to one other manu-

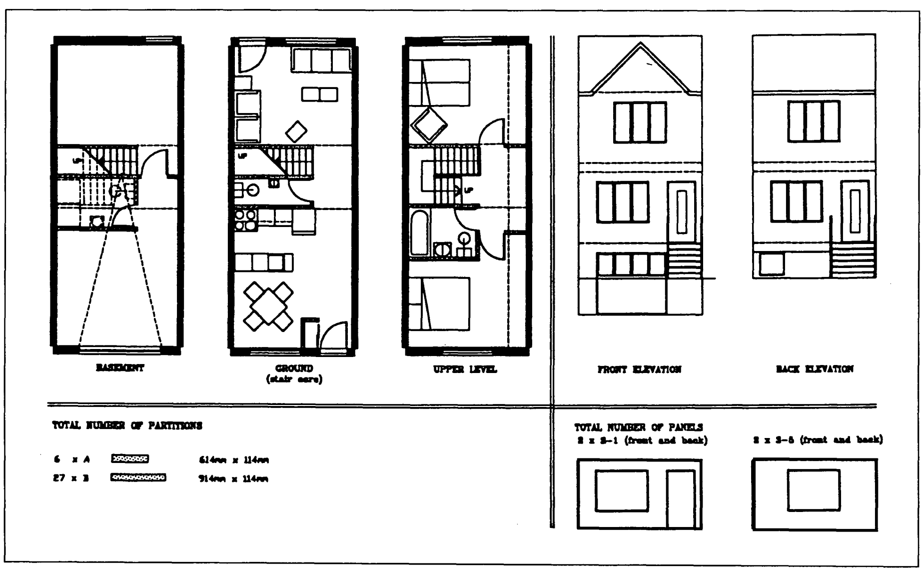

Figure. 8 Components required for sample plan and elevation.

facturer specializing in prefabricated floor systems. Fabricators were asked to submit costs for the following items: material (wall panels), labor (estimated site labor required), electrical (estimated increase or decrease in electrical work), and transportation requirements and associated costs. Costs for one, 10, and 30 units were requested. Other prefabricated elements available from the manufacturers were also investigated, including prefabricated roofs, floors, basements, partitions, and stairs. The cost of "added value" panel systems was also requested, whereby sheathing, siding, gypsum wallboard, and electrical wiring are installed or supplied by the manufacturer.

The estimated costs were compared with those obtained from seven builders who had completed Grow Home type projects in Montreal. For conventional construction, it is generally accepted that a discount of 10% on material and labour can be obtained with as few as 10 units, although this figure does not increase substantially with additional units. This estimate is supported by data obtained from the builders, all of whom reported having received discounts of 10% despite the fact that the number of units under construction ranged from 12 to 78 units. Costs per unit for both 10 and 30 units were therefore estimated at $51,948.

Estimates revealed savings ranging from $2,400 to $3,600 per unit. With transportation costs included, these savings were reduced to $1,900 and $3,400, respectively. The increased savings may provide some incentive for builders, particularly when compounded for multiple units. In quantities of 30 units or more, savings of up to $95,000 might be achieved.

Open-sheathed panel systems provided economies of $44,000 in quantities of 30 units or more, while structural sandwich panels with integrated wood exterior finishes were priced $72,000 lower when compared with homes finished with aluminum siding. With the exception of the unsheathed structural panels with no air space, the proprietary floor system was included in all of the combined systems.

Conclusions

The Grow Home, was designed in response to a need for compact, affordable housing. Within five years of the demonstration of the prototype unit on the university campus in 1990, 6,000 units in 25 projects were built in the Montreal area, with prices ranging from $69,000 to $95,000. The popularity of the Grow Home was due to the fact that a house with a cost of $76,000 could be purchased by a household with an annual income of just over $23,000.

A framework for the industrialization of the Grow Home was developed by adapting the unit's design to make it more suitable to the fabrication process. The design process was aimed at providing sufficient flexibility for the builder, and economies of scale for the manufacturer, by generating a wide range of options for the dwelling using a small number of simple, standard components. Architectural, modular, and technical design criteria were established based on feedback from manufacturers, builders, and occupants of existing Grow Home projects. Although no prefabricated system can equal the flexibility of stick-build construction, the number of options generated for the interior plan with a limited number of standard components provided sufficient selection for interior layouts and exterior elevations. Nine panel configurations were proposed in all: six for the front and back elevations and three for the side walls of the end units. The panels could be combined in various ways to accommodate the options for interior layout. Rowhouse versions of the home could be built with anywhere from two to four panels, while semi-detached or end units would require three to six. The use of small, standard interior partitions generated various configurations for entrances and bathrooms, while enabling on-site changes to be made fairly easily in response to a client's request.

Costs for both conventional construction and prefabricated panel systems were estimated in order to determine whether significant savings could be achieved with prefabrication using adapted versions of the Grow Home. The possibility of integrating other prefabricated components available from the panel manufacturers was also investigated, as were transportation costs. Estimates revealed savings ranging from $2,400 to $3,600 per unit (with transportation costs included, these savings were reduced to $1,900 and $3,400, respectively). The increased savings might provide some incentive for builders, particularly for multiple units. In quantities of 30 units or more, savings of up to $95,000 could be achieved.

As is the case with the introduction of any new product, the challenge lies in educating both the builder and the buyer on the advantages of prefabricated construction. The consumer needs to the instructed on the potential energy savings to be gained from air-tight construction, while the builder needs to be made aware that prefabrication may result in less material wastage and lower expenses for clean-up and trash removal. The accelerated assembly process could translate into savings in overhead and finance costs. Specialized labor requirements are reduced, as are warranty commitments, which are passed on to the manufacturer. In the prefabricated building process, construction tasks can be simplified and managerial burdens relieved.

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References

Automated Builder Magazine. (1992, December). Ventura, CA: BPA International.

Baristow, D. (1985). *Opportunities for manufactured housing in Canada*. Ottawa: Canada Mortgage and Housing Corporation.

Canadian Manufactured Housing Institute (CMHI) (1998). *1997 Annual Report*. Ottawa: CMHI.

Cooke, J. R. (January 29, 1993). Speech delivered to the New Brunswick Mobile Home and Parks Association Annual General Meeting, St. John.

Friedman, A. (1994, second quarter). Narrow-front housing projects as affordability solutions. *Canadian Housing Markets*, Catalogue No. NHA 6354 CHM 94B, 6-7.

Friedman, A., & Cammalleri, V. (1993). Occupant satisfaction with narrow-front starter homes in Montreal. *Housing and Society*, *20* (1), 51-62.

Friedman, A., & Cammalleri, V. (1992). *Evaluation of affordable housing projects based on the Grow Home concept*. Montreal: McGill School of Architecture, Affordable Homes Program.

Kjeldsen, M. (1988). *Industrialized housing in Denmark*. Copenhagen: Danish Building Centre.

Rybczynski, W., Friedman, A. & Ross, S. (1990). *The Grow Home*. Montreal: McGill School of Architecture, Affordable Homes Program.

Robinson, S. (1988). *Manufactured housing: What it is, where it is, how it operates*. Barrington, IL: Ingleside Publishing.