agement focuses on meeting timelines through additional labor or incentives, but with little information about construction difficulties fed back to the product/process designers.

Home builders producing large numbers of a single model often invest additional time in the first few models produced to "iron out" conflicts in the complex interrelationships between the many stages of construction, material handling, the design, and production time.

Time- and space-based (linear) scheduling

The traditional bar graph is no longer able to address these complex interrelationships between stages of construction, crew locations, materials handling, and construction progress (Ragolia et al. 1998). Sequencing of starting dates and completion dates for each stage of the work is especially critical in housing production, as the physical spaces being constructed constrict the number of crews able to work in one space simultaneously. Time- and space-based scheduling adds a layer of "where" information to the "who," "what," and "when" information from the bar chart, while retaining the logic of a critical path–sequencing diagram. A decision on the fundamental unit of space becomes the vertical increment of the time and space schedule. This may be a whole house in a larger development or an individual apartment in a multifamily project.

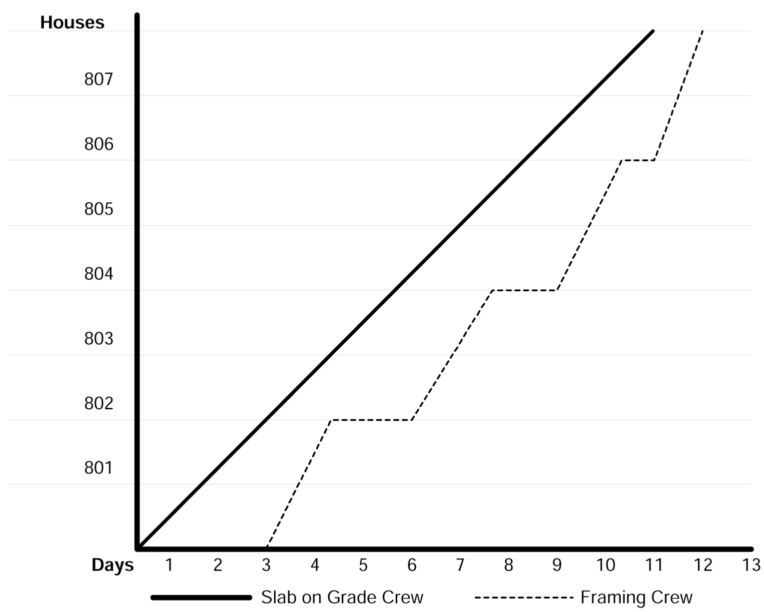

Figure 3.7: Linear scheduling graph of ideal production rate, actual start, and finish dates for framing.

The fundamental principle is that the project manager allocates specific spaces to construction crews in a closely organized sequence along a time line (see Figure 3.6). In this example, the slab-on-grade crew is moving continuously from house #801 to house #815. By day 4, the slab at house #803 is complete. To allow the slab two days to cure, the framing crew does not begin erecting wall panels at house 803 until day 6. The construction manager assigns the degree of continuity or discontinuity of work for each task based on the overall goals for the construction (optimize time, labor, equipment, etc.) and production rates. Time- and space-scheduling supports JIT strategies for material purchases and handling (50 sheets of drywall delivered to a specific house on a specific day), minimizing weatherrelated material damage, pilfering, and allocation of additional site labor to moving materials multiple times.

This visual integration of information provides a construction manager the ability to schedule and monitor construction activities with greater detail, decreasing space and time conflicts between crews, increasing safety, and increasing production as a whole.

USE OF MATERIALS INCORPORATING THE PERFORMANCE OF MANY DISCRETE PARTS INTO ONE MATERIAL

Structural insulated panel systems

Another strategy for integrating discrete construction and fabrication processes is the replacement of multiple materials with a single product performing the same duties. An example would be a light wood-framed exterior wall assembly (OSB, studs, plates, insulation, gypsum board) being replaced by structural insulated panel (SIP) systems. SIPs are manufactured with structural panel products (OSB, plywood) on one or two faces, with foam plastic insulation bonded to the structural panels. When installed, the two panels are joined along their sides with a variety of spline details (which vary from manufacturer to manufacturer). The bonding process (and subsequent structural capacity) of the foam-plastic insulation also varies among manufacturers. Some manually apply adhesive to preformed foam-plastic sheets, then press the structural panels onto the adhesive; others extrude the foam-plastic insulation in place between the structural panels. Both thermal and structural performance varies according to type of foam plastic (expanded polystyrene [EPS], extruded polystyrene, and polyisocyanurate). Costs and thermal "R" values are less per inch of SIP thickness with EPS and more with polyisocyanurate.

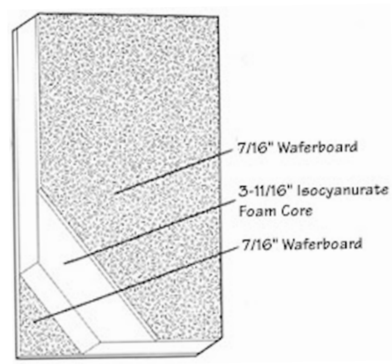

Figure 3.8: Structural insulated panel
Source: Winter Panel Corporation

The SIP primarily reduces on-site labor. Capitalizing the costs of engineering, testing, labor, machinery, marketing, and approvals makes these products slightly more expensive than the on-site fabrication of the discrete pieces. At this time, SIPs represent a small but growing market and are used as both primary structure for houses and as cladding for heavy, timber-framed houses. As on-site costs for labor and materials rise and start-up costs for the SIP industry are amortized, these panels should make steady gains in market share. Recent SIP technological advances include integration of raceway within the foam-plastic core for routing electrical wiring and the development of cam locks between panels to address difficulty in aligning panel splines along the sides of the SIP.

Insulating concrete form systems

Another construction system that assembles functions normally fabricated by a number of discrete pieces and processes into a more simplified process is the insulating concrete form (ICF) system. This system combines the formwork (traditionally constructed of two faces, a steel tie, steel reinforcing, vertical and horizontal ribbing, external bracing), internal insulation, plates, and studs to attach finish materials into one process.

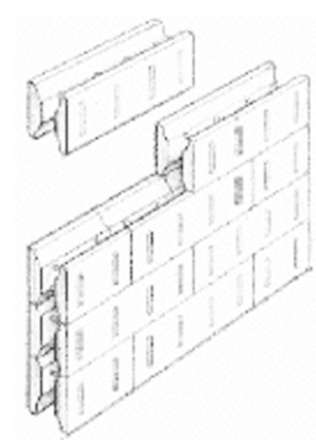

Figure 3.9: Insulated concrete form
Source: Winter Panel Corporation

ICFs have emerged as a construction method addressing thermal performance, shortages of skilled labor, and reduction of construction time. There are over 40 different manufacturers of ICFs (Engel 1999). ICFs can make three different types of reinforced concrete wall: the flat wall, similar to reinforced-concrete walls formed between the faces of wood or metal forms; the grid wall, with vertical and horizontal chambers of reinforced concrete evenly distributed across the foundation; and the post-and-beam wall, having more vertical and fewer reinforced horizontal beams. The post-and-beam wall is used primarily above grade. The ICF itself is made of expanded or extruded polystyrene foam insulation for the most part, with some manufacturers offering cement composite, wood, and plastic ICFs. The forms are shipped as blocks, planks, or panel forms, all requiring some form of exterior bracing during the pouring process.

Problems arising from the use of ICFs are mostly related to layout, aggressive vibration, or inadequate bracing contributing to form shifting and blowouts during concrete placing. Blowouts typically result from use of high-slump concrete or improper placement. Questions about the ability of insect pests to utilize the foam as an easy passage to the wood framing above have led manufacturers to require the foam face above grade to be removed after concrete curing to interrupt a termite or carpenter ant path through the foam. These inspection strips provide homeowners and inspectors the ability to observe termite tubes and paths forming on the inspection strip and take appropriate remedial action (NAHBRC 1997).

Precast foundation systems

With excavation and foundation costs making up 9–12 percent of total construction costs, foundation systems have been closely examined for their potential to contribute to increased affordability. Within the strategy of industrialized systems, which have fewer parts and processes required for installation (simplifying construction), manufacturers of precast concrete products have introduced precast foundation panel products into the residential construction market.

Unlike the simple slab type of precast concrete panels commonly seen on commercial construction sites, these foundation systems make every effort to minimize the amount of concrete in the panel. This efficiency is most often achieved by using more complex formwork to produce a ribbed panel. The resulting elimination of material between the ribbing leaves a stiff panel assembly with lower material costs, but more importantly, a panel of lower weight. The weight reduction enables more panels to be shipped per truck, and consequently fewer trips per home site.

These panels combine the functions of the foundation wall, are preinsulated with EPS foam plastic, have built-in places for electrical wiring, and have integral nailing surfaces for attaching interior finishes. The use of EPS is limited to the interior surface of the panel. This configuration, combined with solid concrete surfaces where the panel attaches to the footing below and wood framing above, minimizes the paths for insect pests from the ground to the wood framing. Being a closed-cell foam, EPS holds minimal moisture and does not appear to develop mold and mildew.

The solid surface of concrete at the base of the panel works with steel connectors between panels to make a rigid concrete wall, eliminating the need for a separate, poured footing and foundation in most soil conditions. High-performance urethane sealant is specified at joints between panels. Combined with the large panel sizes (up to 18 feet long and 8 feet tall), this sealant provides a foundation wall with fewer through joints than a standard masonry block wall and thus higher moisture resistance.

Single truck shipments carry up to 155 linear feet of foundation wall, which is erected on a screeded, compacted, crushed-stone base. Installation includes the preparation, compaction, and leveling of the base (usually one working day) and erection of the panels (usually one-half working day for a building with a simple footprint).

CONCLUSIONS

Each condition of integration requires a complex understanding of residential subsystems, components, behavior, and relationships to the whole house. As housing construction has become more complex and as the production and operation of the house have become more complex, the ability for one person to maintain command of the interrelationships between subsystems has greatly diminished.

A carefully developed data structure and data path—beginning at the design concept and following the house development through analysis, construction, operation, and finally recycling—seems the most likely tool to underpin each condition of integration. This first step, information integration, will be the key enabler to the four other conditions of integration. The next chapter discusses implementation strategies for information integration. From this base, we can develop a prioritized plan for industrialization of the home building industry.