# An Open Building Strategy for Balancing Production Efficiency and Consumer Choice in Housing

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**Abstract**

This paper suggests that market pressures for both production efficiency and consumer choice, and nascent trends in the housing supply channels, point to early adoption of an Open Building approach to residential construction. An important opportunity toward this end lies in the trend toward factory-based product bundling or kitting. The paper suggests how development of this trend – supported by analysis of failures of 20th century efforts to harness industrial production for housing – can contribute to significant innovation in house building. The key to such a strategy is to divide the "whole house" process and product into two decision/technical clusters called Shell (or base building) and Infill (or fit-out). Each responds to specific but distinct decision constraints, regulatory environments and market dynamics: the shell responds to local conditions and regulations and the infill can be approved at a more general level (e.g. UL labeling). The development of Shell/Infill design methods, and production logistics for integrated infill product kits, are recommended for further research and business development.

**Keywords:** Open Building, Shell/Infill Housing, Work Restructuring, Whole House Design, Supply Chain Management

## Introduction

The 20th century record of efforts in the United States to fully harness the power of industrial production in the service of market-oriented housing is replete with failures. (Bender, 1973; Carreiro, 1968; Hounshell, 1984; Kelly, 1959; Nelkin, 1971; Russell, 1981; Sullivan, 1980). Several lessons can be drawn from a reading of that history. **First**, housing is not only concerned with engineering and hardware, but has public interest, business and market dimensions. **Second,** responsibility for housing decisions is widely distributed and includes the user or occupant. **Third**, housing must fit its local context – a small range of solutions is not applicable everywhere. **Fourth,** housing is not a rigid "product" but changes over time. **Fifth,** the distinction between construction on the one hand and industrial production on the other is crucial to making effective use of both.

Continued misapprehension of these lessons has thwarted the full harnessing of industrial production in the service of higher quality, more durable yet adjustable and consumer-oriented housing. Recently, the Federal Government's PATH program has attempted to advance housing technology in cooperation with private industry and the National Science Foundation. One part of the PATH program - WHOLE HOUSE AND DESIGN PROCESS REDESIGN - is particularly interesting and its goals should be cited, to wit:

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?? Integrating various subsystems or components to optimize design and operation
?? Integrating functions of various components or subsystems in a home
?? Modifying the management approach and/or other processes to simplify the schedule, reduce negative interdependencies and simplify construction
?? Expanding the use of factory-built assemblies including whole-building systems.

This paper suggests that the PATH goal of whole house and building process redesign will benefit from careful study of an OPEN BUILDING approach.

**State of the Art: Open Building**

The Open Building approach is a "way of working" that divides the total process and product of house construction into two decision levels. (Kendall, 2002, 2001, 1999, 1996) For illustrative purposes I will use a townhouse in which one part is called the **shell or base building**, and the other is called the **infill or fit-out**. The shell is the result of design decisions specific to the site, constrained by local regulations and conventions, geotechnical and environmental conditions. The infill is the set of design decisions and products needed to make a shell habitable and changeable later without disturbing the shell. Given a particular shell design, a variety of interior layouts, equipment and finish choices are available on a menu basis or are custom designed using a set of design tools and technical rules. The first goal is to meet individual buyer preferences and budgets, initially and over time. The second goal is to enable a developer to defer specific unit decisions until the point of sale or lease, without risk. Decision flexibility is possible because of the separation of shell and infill, and the use of infill "kits".

The exact determination of what spaces and parts belong to the "shell" and which to the "infill" will be somewhat different in each project, and is independent of architectural style or typology. Generally, the shell includes the foundations, building structure and envelope, stairs, and main MEP systems. The infill includes partitions, fixtures, cabinets and finishes, and the parts of the MEP systems specific to that floor plan including plumbing fixtures.

When the decision is made on the specific infill layout (by the occupant or by the developer), the parts specified for it are prepared as a ready-to-assemble (RTA) "infill kit" in an off-site fabrication facility and installed in the shell at an agreed upon cost and schedule. This offers the developer a reduction of risk by avoiding the need to "peg" the market prematurely, and offers the buyer significant choice "behind the front door", unavailable in conventional "integrated" production and decision processes.

This approach is based on the following principles:

•*The idea of distinct levels of intervention in the built environment, such as those represented by 'shell' and 'infill' (as these terms are used conventionally in office building and shopping center design and construction), or by urban design and architecture.*

• *The idea that users / inhabitants must be able to make design decisions, as well as professionals.*

• *The idea that interfaces between technical systems should allow the replacement of one system with another performing the same function. (As with different infill systems applied in a given shell).*

• *The idea that built environment – including housing - is in constant transformation and change must be recognized and understood.* (Habraken, www.habraken.com)

These ideas constitute a major departure from traditional housing delivery methods. They have been studied and applied worldwide for the past three decades, particularly in multi-unit residential construction. (Kendall, 1999) It is in that housing type that problems of legal conflict, financial risk, decision flexibility and decision deferment are most pressing and achieving long-term facility adaptability is most difficult. Such capabilities are necessary to meet current and future dynamics in demographics and life styles and well as rapid changes in technical systems related to life style changes and technical innovation.

This paper proposes that this idea, heretofore studied and applied to multi-unit projects, should be applied to single family attached or detached residential construction. (Kendall, 2002)

## Analyzing Trends

Businesses in the housing delivery supply chain are adopting "product and service bundling" and "kitting" strategies. This means that product manufacturers and service providers are joining forces or aggregating control, to "add value' and gain competitive advantage in the supply constellations by preparing packages of building parts off-site, for easy on-site installation. This combines products and services. Sometimes this is called "kitting", for example when an electrical contractor pre-wires all the boxes and terminations in the shop, packages everything needed for the entire wiring installation, brings them to the site and installs them.

"Product bundling" or "kitting" concerns reconfiguring supply channel management and logistics by forming new alliances, virtual companies, or by securing "vertical control" of some part of a supply constellation. It is one strategy to deliver construction effectively, on time and with a competitive cost – quality ratio, with increased emphasis on service.

The term product bundling can have several meanings. One is characterized by the legal battle involving Microsoft, charged with monopolistic practices by its "bundling" several discrete pieces of software into a unified package the parts of which cannot be purchased separately. The business literature concentrates on this definition.

In the context of the building industry this concept refers to bringing together a number of discrete products (made or purchased) and services into one coordinated package by a single company. Normally, this process occurs at a distance from the site of final installation, signifying that "value" is added both off-site (in preparing the bundle or kit) and on-site (in installing it).

Product bundling is similar to prefabrication, which means assembling elements off-site to be installed as a whole when it reaches the construction site it was prepared for. Product bundling or kitting focuses on the delivery of packages of parts that are **READY TO ASSEMBLE**, connoting the idea of boxes of parts small enough to put in a panel van and through the front door of the house (or the elevator of a high-rise residential building).

This is not new. Examples of "product bundles" are a Pella sunroom brought to the site in boxes; a complete kitchen from IKEA; or a plastic-wrapped toilet bowl valve replacement kit. Often, these products are not made entirely by the company doing the bundling (although they can be), but may be products brought together from a variety of manufacturers or suppliers.

It is characteristic of a "product bundle" that it arrives at the site (largely) ready for assembly, rather than pre-assembled. This means that further value must be added at the site, but that the on-site assembly work is facilitated by the bundling together of just the right parts "designed for assembly" and sometimes also including the tools for the job.

**Kinds of Kits or Bundles**

One kind of 'product bundle' is **"project independent".** Such bundles are made at a distance from the site where they will be used. The product is not made for a specific project but for ANY project – that is, it is made at the initiative of the producer, for a particular market segment, and is made at the producer's risk. Examples of this are a Velux roof window kit; a lighting fixture with all the cables, hangers, fasteners, etc in the box; a passage door hardware kit with a variety of strikes and other parts to fit a variety of door installation conditions; a faucet/ drain/ overflow kit; and so on. This is an example of product "push".

The other kind of "product bundle" is **"project dependent."** Also made in a controlled environment at a distance from the building site, on-site assembly is faster with increased quality and reduced dependence on site labor. This kind of production is initiated for the project at hand and occurs at the user's risk. Again, the bundle is "ready-to-assemble" when it reaches the site. Such "project dependent" bundles can and usually do use manufactured parts made for the market, and brought together (cut, bent, shaped, assembled) for the particular installation. Examples include a sunroom extension from a local window/patio enclosure company; a set of kitchen cabinets the selection of which is specific to the job at hand; or a panelized house package. This is an example of market "pull".

The key distinction is which party takes initiative – the maker or the user. In the former the producer takes the initiative and risk. In the latter, the user takes initiative and assumes risk.

**Number of Parts and Complexity**

A major question for both the party making the bundle and the party using it is the number of parts and services in a bundle or kit, and the number of different product types in it.

For example, a MASCO company provides installed insulation services. This "bundle" offers a number of discrete products obtained from different suppliers: the insulation product, "RAFT-R-MATE®" or equal insulation baffle, and the blower machine, etc and the installation service. Another company provides kitchen cabinet sets, "kits" that include products brought together (some waiting to be assembled and some provided in assembled form) from a number of suppliers (hinges, glides, cabinet inserts, counters, counters, etc).

Another example is a kitchen re-modeler. This specialized builder is a master of “bundling” or “kitting”. Such a builder knows how to prepare as much as possible before arriving at the job site. This reduces on-site waste, avoids missing parts and trips to various supply houses, streamlines the job and achieves quality control in ways difficult to accomplish when the job is organized piecemeal and by multiple independent subcontractors.

**Who Installs the Bundle or Kit?**

A second question concerns installation. Skills are involved, but also potential issues of trade jurisdiction. In the case of a residential “infill kit”, the problem is that if each “kit” is delivered as a complete package for a given dwelling unit, it makes no sense for the traditional sequencing of trades to come to work on its installation: e.g. for a carpenter to come to the unit, install the framing, then leave to install the framing in another unit with its “kit”, then return later to hang drywall after the electrician has completed his rough-in, and so on. This conventional method asks for problems in maintaining uninterrupted and efficient installation work.

Where labor union practices are enforced, the production and installation of “bundles” will be governed by the traditional labor jurisdictions. It appears that unless a new kind of labor craft emerges – a multi-skilled “installer” - the unions will thwart the kind of skill bundling that must accompany product bundling.

Where merit shop contractors operate, the issue of trade jurisdiction does not appear. In such cases, the principle concern is the availability of teams of workers with required skills to manage the installation of the parts. Multi-skilled workers are essential to avoid inefficient utilization of manpower. Given this, bundles or kits can be designed along with the training program for the installers – thus linking innovation in both products and labor skill sets.

**Whole Building Product Bundles or Kits**

The idea of “whole house” kits is familiar and has been for more than 100 years, including Sears Catalogue homes. (Sears, Roebuck, 1990, 1991) Sears houses were available for more than 50 years. But most experiments failed because they were out of touch with the market, lost competitive advantage, and failed to distinguish “architecture” from “production methods”. One case of the latter is the Lustron House, only several thousands of which were built after very large private and public sector investments. (Herbert, 1984) As **Figure 1** indicates, the entire house was “kitted” in a factory, and assembled on-site by a team of five assemblers.

**Techbuilt**

Designed by architect Carl Koch in 1952, the Techbuilt house was a “prefabricated” house using ordinary wood framing for the exterior wall and an interior post and beam structure supporting prefabricated floor panels. The company operated between 1952-67. Each house “kit” was produced in a factory only upon completion of the drawings and a signed contract. The entire package was delivered by truck, including roof panels, wall panels with windows and exterior doors, kitchen cabinets, furnace, baseboard heating elements, and the roofing materials. Siding, fixed glass, electric service and plumbing were obtained locally. All parts - including those delivered by Techbuilt - were assembled by a local contractor with a Techbuilt advisor on-site until the shell was enclosed. (Kelly, 1959)

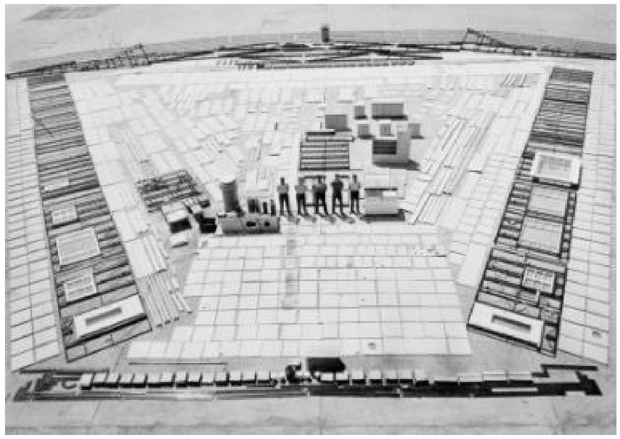

**Figure 1:** A Lustron house "kit" spread out on an airport runway to demonstrate the extensive contents of a Lustron House kit of parts. (ca 1950)

**Figure 2**: Delivery of Techbuilt kit

**Figure 3**: Erection of a house

**Bensonwood Homes**

Bensonwood Homes, a leading timber frame homebuilder, has long been an innovator in that market. They have successfully implemented an OPEN BUILT ® approach. It organizes the design and construction process according to "packages". Each "package" is delivered to the site in sequence and installed. Each package is composed of products made by Bensonwood Homes in their own fabrication shops (timber frame, exterior skin panels, doors, etc) and products made by other companies (cables, boxes, ducts, fixtures, hardware, glass, etc). (www.bensonwoodhomes.com)

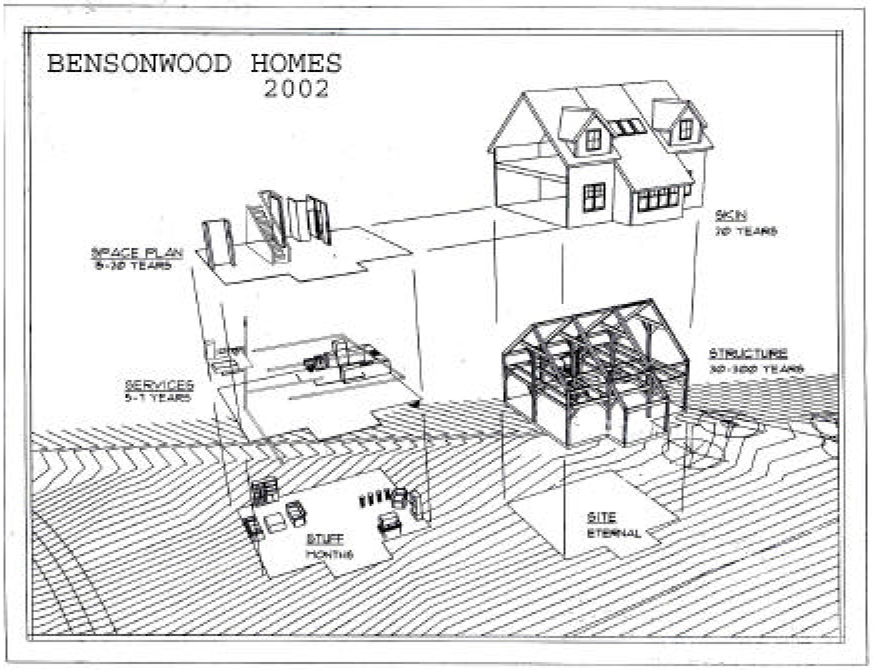


**Figure 4:** This diagram indicates the main subsystems, drawn from Stewart Brand's book How Buildings Learn.

**Implementing an Open Building Approach Thru Infill Kits**

I will now discuss how to meet PATH goals of WHOLE HOUSE and BUILDING PROCESS REDESIGN of single - family houses (detached or attached) in the United States using an Open Building process. The "whole house" is divided into two "levels" or "decision /technology bundles" as follows:

a. **THE SERVICED SHELL or BASE BUILDING:** This is the decision / technology bundle tied to the site, arguably the more permanent part of the whole house and the part most tied to local politics and regulatory constraints. This includes the "public" matters including geotechnical, environmental, public utility and regulatory contexts, all of which must recognize a number of technical, public health, safety and welfare issues as well as constraints such as urban design or historic design rules, as well as local traditions and conditions in the financing arena. It also may include preferences (or requirements) of materials, building styles, methods of building and labor practices. It can be factory produced or stick-built on-site and can be made of any suitable materials. It should be energy efficient and provide accommodation capacity for a range of interior layouts.
b. **THE INFILL or FIT-OUT:** This is the decision / technology bundle constituting the more consumer oriented and changeable part of the house. This includes the "private" decisions ("everything behind my front door") including fixtures, finishes, cabinets, part of the MEP equipment, interior partitions, consumer electronics and IT systems. This is or should be - generally speaking - the "class" of technologies and decisions that do not require local regulatory approval, that may be of the "do-it-yourself" category, that change on a cycle of 5-20 years, and that may have UL labels or their equivalent.

**The Problem of Differences of Supply (Push) and Demand (Pull)**

Developers know that consumers often prefer changes of standard floor plans normally offered to them. Even if a specific floor plan is preferred from the menu of options in a house with the right size, style, location and price, a customer may want to change a door's location to enable the family to move in a favorite piece of furniture. Or, the customer may want a wall in a different position, or may want two separate bathrooms on the second floor, or a larger kitchen. Frequently, consumers want to select bathroom and kitchen equipment and finishes.

If competition in the market is strong, developers have to give in to consumer demand more quickly than when demand is weak. But if they could, developers would not offer any choice because it will cost them money. It is not clear that the cost of customization can be passed on to the buyer. Typically, the contractor's pricing is based on fixed floor plans (quantities) and specifications. Any change will be disruptive to their entire estimating, production, delivery and management processes.

Contractors also know that developers frequently demand floor plan changes, because they fear that otherwise some units will not be sold. This puts the contractor at an advantage over the developer to negotiate prices of the change. But it is also true that it is difficult for the contractor to manage such changes and to determine their exact cost. Higher prices will usually be established accordingly, to cover uncertainties.

This familiar situation basically puts developers, builders and homebuyers on a collision course. The tensions and conflicts that are so familiar in this market come from the "disconnect" between demand for customized houses (the market "pull") and the ability of the supply side to deliver. The second source of tension comes years later when the house must be adapted to meet changed homeowner (market) preferences, and the house is found to be so technically entangled that sought-after adjustments cause excessive difficulties, danger and costs.

**Shell / Fit-out: Reconciliation of Conflict**

The Open Building approach of separating the SHELL from the INFILL reconciles this conflict. Returning to the townhouse example, the developer now asks for bids only for the townhouse shell. The product delivered by the contractor is a finished building complete with windows and exterior finishes, and all of the "shell" mechanical systems and services. As such, the building as finished will establish the kind of lifestyle and quality of services that the buyer needs to know before he can decide if the location is attractive. But the inside of the unit will be empty and ready to be filled in. Floors are smooth and ceilings and shell walls are (mostly) finished. At fixed places in each unit there is access to electricity, water, gas, and sewage for the fit-out "kit" to connect to for further distribution in the dwelling unit.

Constructing this "shell" is not difficult for the builder. In fact, the builder is freed of the part of the construction process that usually constitutes the greatest risk to him and takes most of the overhead for on-site management and coordination of subcontractors. It is not difficult to calculate that money is easily lost on finishing the interiors of units where it is gained in setting up the shell. The builder, in short, can now do more with lower overhead.

For his part, the developer knows precisely what he can expect from the builder in terms of product and timing. For the infill "kit", he contracts a qualified "infill" special purpose company, and is now in a position to offer the home buyer exactly what they want and can structure his prices and schedule accordingly.

This approach sets free all parties involved: the homebuyer, the developer and the builder. It also shows how the approach is not only a technical innovation but has very important commercial implications, putting the developer and the builder in a mode of operation that offers superior service to the buyer, in a way that can be well controlled financially and in terms of delivery and logistics. This should give a decidedly competitive advantage over those operating in the traditional mode. (Habraken, 2000)

**System Approach**

This way of seeing the "whole house" is system-based (hierarchically organized parts and their rule-based relations) and sets the stage for accelerated innovation in both the shell and infill. This stage for innovation is available because the infill - the technical bundle that is most closely aligned with the consumer market - is separated from the shell. It is the consumer market that has fueled innovation in other product sectors including electronics and automotive engineering and is one reason that introduction of the INFILL level in housing is critical to innovation.

In this strategy, the technical parts are generally the same in each project - see above points a) and b) - but can also vary somewhat according to architectural style and typology. An Open Building approach means that interdependencies between the two major subsystems – SHELL and INFILL - are reduced to a minimum and those that remain are well organized with explicit positioning and interface standards. But this principle also addresses interfaces between parts in the SHELL and in the INFILL. Thus, a change of one part will cause fewer perturbations than in a conventionally "entangled" house, where, because of excessive interdependencies, innovation in one part requires changes to many other parts. This negative systems behavior itself is a major hindrance to innovation in a highly competitive and disaggregated industry.

**Problems of Entanblement**

Achieving disentanglement has been particularly difficult when considering the increasing numbers and complexity of pipes, wires and ducts in houses, subsystems that have been part of our technical repertoire for the relatively short span of three or four generations. These subsystems have incrementally filled the many available cavities in wood framed houses. We normally accept the idea that the cavities made available by hollow walls and floors of standard platform frame construction are optimally suited as routing channels for such MEP parts. These cavities have, over time, been filled to capacity, and, when filled, we have made the cavities bigger. But this assumption leads to difficulties.

In light of the above, we study the following principles:

**First**, all parts need substitutes that can go in the same position as the part they are replacing with minimal disturbance to adjacent parts.

**Second**, the number of parts for which substitutes must be available is increasing. This results from more and varied homeowner expectations, more regulations and performance requirements. Thus, combining many parts and functions into (higher value added) “integrated” and mass-produced parts is almost never effective. Open Building seeks to develop design methods, coordination and positioning principles, and logistics strategies for parts whose combinations are varied yet systematic.

**Third**, we distinguish two kinds of markets for new products and processes: parts that are deployed as part of the SHELL, and parts that are deployed as part of the FIT-OUT. We make this distinction because the approval processes for new products in each category are (or should become) sufficiently different that they call for different innovation and business strategies.

**Fourth**, buildings that last must be designed and built to change in respect to shifting preferences, demographics and regulations. Since these changes do not occur in uniform cycles, buildings are optimally organized in respect to a RANGE of cycles of change. Consumer appliances, fixtures, cabinets and technical equipment may be changed most frequently (because of premature failure, availability of equipment with improved performance, style changes, etc). Finishes and surfaces (interior and sometimes exterior) are perhaps next in the change cycle. Windows and doors may come next. Spatial subdivisions are perhaps next, occurring on the order of 10 – 20 year cycles on average. It is the latter changes that are most difficult precisely because of the practice of embedding pipes, wires and ducts within walls, partitions and floors.

**Fifth**, true industrial production (where the producer takes initiative and assumes risk, in contrast to construction or prefabrication where the user takes initiative and assumes risk) has been most successful in the production of housing parts with the lowest number of dependency relations, and for which stable positioning and interface standards exist to resolve connection problems between parts. For example, the standard 4” on-center holes in lavatory bowls for faucets has allowed innovation and competitive positioning to occur in the manufacture of both bowls and faucets by independent companies. No such standards exist, for example, regarding the position of wiring and piping within floors and walls, greatly inhibiting innovation in either how walls and floors are made or in the wiring, piping and ducts that are normally buried there. The use of open web wooden trusses is not a solution, but only gives a bigger cavity in which to (usually indiscriminately) distribute piping, wiring and ductwork.

**Recommendation for Future Research**

International Open Building experience offers lessons for US practice, particularly developments in the Netherlands, Finland, and Japan. To a certain extent, the problems are similar. In addition, trends in the United States pointing to these developments – in housing but also in office, retail and other logistics-intensive sectors - are worth studying carefully. Several actions are therefore recommended.

FIRST, funding must be made available for a series of demonstration projects to illustrate the separation between SHELL and INFILL. Initially, EXISTING PRODUCTS should be used. Cut-away portions of the construction can reveal difficult technical interfaces and point out how they relate to the principles noted above.

SECOND, in other demonstration projects, CONDITIONS IN HOUSEBUILDING RIPE FOR PRODUCT AND PROCESS INNOVATION FROM AN OPEN BUILDING PERSPECTIVE should be showcased, including solutions developed and used in other countries.

THIRD, demonstrations are needed to explore the new logistics suggested by the "infill kit" concept. The problem of multi-skilled installation teams should be studied. (Christopher, 1998) (Figure 5, 6 and 7)

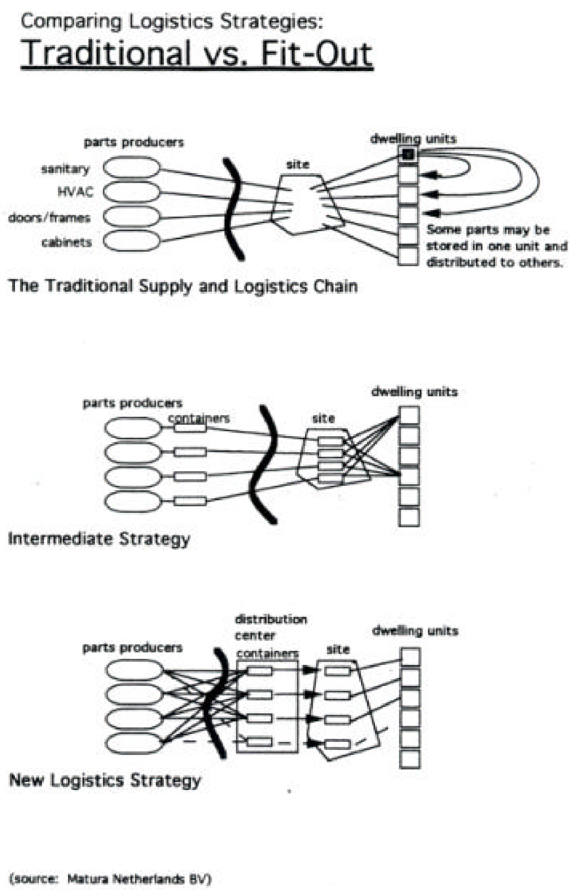


*Figure 5*: Diagram developed by Matura International to describe their approach to a **new logistics strategy**.

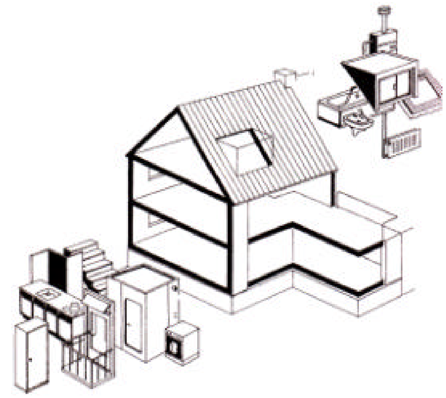

*Figure 6*: Shell/Infill distinction

***llustratiion 7***: An "infill" kitting facility

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