PATH TECHNOLOGY ROADMAPPING

WHOLE HOUSE AND BUILDING PROCESS REDESIGN

BACKGROUND PAPER

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1. INTRODUCTION

This paper addresses Whole House and Building Process Redesign in residential construction. It has been prepared for participants in a technology brainstorming session that will take a broad view of the way homes are designed and constructed. The session is being organized by the NAHB Research Center in conjunction with the "Partnership for Advancing Technology in Housing" (PATH). PATH is a public-private partnership that was created to improve new and existing American homes in several important ways between now and the year 2010.

PATH Program Goals

- ✭ *reduce the monthly cost of new housing by 20 percent or more*
- ✭ *cut the environmental impact and energy use of new housing by 50 percent or more and reduce energy use in at least 15 million existing homes by 30 percent or more*
- ✭ *improve durability and reduce maintenance costs by 50 percent, and*
- ✭ *reduce by at least 10 percent the risk of loss of life, injury, and property destruction from natural hazards and decrease by at least 20 percent residential construction work illnesses and injuries.*

The objective of PATH technology roadmapping is to identify potential technologies that can, in combination, allow the building industry to achieve the PATH goals by 2010 and to define specific, time-phased research and development activities required to implement these technologies. The PATH Roadmaps are intended to help coordinate and leverage private sector and public sector R&D for maximum benefits. The completed roadmaps will:

- ✓ Provide a common, shared vision among the public and private sectors of how the technology, if effectively implemented, will benefit the industry;
- ✓ Serve as a guide for public and private sector investment in R&D;
- ✓ Provide direction to public sector, private sector, and academia on needed research and development; and,
- ✓ Facilitate or encourage joint private/public sector activities that will reduce or eliminate barriers to achieving the vision -- e.g. development of connection and panel standards to speed construction.

More information about PATH, including its technology outreach and technology roadmapping activities, appears in Appendix A.

PATH roadmapping work began in March 2000 with a two-day "brainstorming" session where a cross-section of industry experts identified 40 "Technology Options" and evaluated the options as candidates for roadmap development. Four of the technology options listed below addressed rethinking of the way a house or its major subsystems are designed or constructed:

- Modular, whole house systems
- Whole house process redesign
- Flexible, adaptable space
- Mechanical system disentangling/integration

These four were consolidated into a Whole House and Building Process Redesign "Technology Portfolio" with high potential value in achieving PATH goals. The roadmapping activity to be initiated on March 28, 2001 will address this important area, an area which is very broad and encourages out of the box systems thinking and could ultimately provide a huge contribution to achieving the PATH goals.

2. BACKGROUND - CURRENT SITUATION

The home is the centerpiece of the typical American family. In 1999, over 66 percent of American households owned their own home. Homeownership is an important way for Americans to accumulate wealth - home equity accounts for more than half of the total net worth of the typical home-owning family.

Unfortunately, houses are becoming less affordable. NAHB analysis of department of commerce statistics indicate that the median cost of houses increased 32% from 1992 to 1997 while the median salaries increased only 24%. While the durability of houses is open to debate, the perception that houses are less durable is persistent. For home builders', the challenge of building affordable, durable homes becomes ever more challenging, as the labor pool shrinks and the cost of materials and land development increases.

Fragmentation of the industry remains a fact. The housing industry, although the seventh largest industry in the US, is a disparate operation comprised of thousands of loosely linked entities engaged in hundreds of separate tasks. Conditions resemble those in the early days of the automobile industry, before it was transformed from a cottage industry by the "fixed frame" and "interchangeable parts" concept of Henry Ford.

As a business, the home building industry remains highly fragmented and is typified by small builders managing many small trade contractors. According to "Structure of the Residential Construction Industry," October 2000, by Gopal Ahluwalia and Jo Chapman, NAHB Housing Economics, the 1997 Census of Construction shows the following:

> In spite of mergers and acquisitions, the number of residential contractors grew from 131,000 in 1992 to 145,000 in 1997. Of the 145,000, about 46,000 did remodeling only, so that there were 99,000 contractors building a total of approximately 1.2 million units. That averages to about 12 units per builder.
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> The data further indicates that 73,500 builders built less than 25 homes, but accounted for 39% of the homes built. Builders in this category have an average of only 4 employees on the payroll. Builders who build less than 100 units accounted for another 21% of the houses and had an average of 8 employees on their payroll. This means that 60% of the houses are built by companies who build less than 100 houses per year and have an average of less than 8 people on their payrolls.

As indicated by the small number of employees in a home building firm, the vast majority of home builders place little reliance on in-house labor crews. Instead, they focus on meeting customer needs by orchestrating the labor of a host of subcontractors and dealing with a wide range of suppliers and third parties. Accordingly, they manage and oversee not only key activities carried out within the firm but also the activities of subcontractors and other participants in the supply chain. The management of key activities affects schedule, costs, prices, and profitability as well as performance of the end product. Good management of the home building process can easily make the difference between success and failure in a highly competitive environment

Mass production is, for the most part, not happening in the industry. Every house is built "one-off", literally the result of trial and error process, colored by a myriad of factors, including;

- use of independent trade persons with wide variety and levels of skill,
- localized building codes where standards have evolved into a vernacular system with no real predictability,
- individual preferences and practices where piecework is the mindset - not systems integration.

This lack of uniformity occurs because there are no common, repeatable standard dimensions, standard repeatable protocols and no integration of these systems with one another or among other building systems.

Many large builders limit their product line to only a few basic designs. In theory this allows the houses to be built more cost effectively, but in practice this doesn't often happen. How wiring, plumbing and mechanical systems are installed and routed is typically determined by the personal preferences of the particular trades-person doing the installation. For example, the HVAC ducts may be installed in a way that makes plumbing difficult.

A small "custom" builder will work a plan over and over again changing the façade or elevation, bumping out here or there, moving an inside wall or two, adding 2 feet here or there, changing material choices, all while giving the impression this is a custom house from scratch. They do this because they know the costs of that footprint or shell (60-65% of the total), that leaves 30-35% variable cost on finish choices, added features, with optional items tacked on above that.

Maintaining competitive costs without systems thinking is a losing proposition. Today most builders only know how to attack the material side of total or aggregate cost, especially as shortages of labor, drive up labor costs. Most gains to be made in material costs (or cut in this case) are in that 60-65% "fixed or known cost " of the footprint/shell category. Consumers still want the features and finish items, and the builder needs to have those to compete. They cut material cost with cheaper substitutes, press supplier and manufacturer on cost and attempt to find cheaper labor - still doing the same amount of work but for less, or doing it faster, or doing the same work with fewer people. This singular approach only accelerates the durability problems caused by "cheaper" materials, poorly installed, which as they fail, drive greater inspection and regulatory mandates. Furthermore, this singular approach drives more products to "commodity" status, as prices are hammered down and product features are stripped away. Suppliers of commodities have little control over their destiny. As the market consolidates, inevitable in all mature industries, suppliers/manufacturers face intensified competition, pricing pressure, and declining economic performance- scenarios that don't play well on Wall Street or in the boardroom. It's a spiraling, accelerating, frustrating situation at best, for all involved. And it is getting worse.

As the labor deficit continues to widen along with escalating costs of construction, builders continue to buy "cheaper" products, installed with less skilled, less trained labor. The manufacturer, forced to lower price points, cuts material costs (80% of a products aggregate cost), strips away features, puts less engineering and R&D into products, reduces services, adds more fine print to warranties. The result, homeowners and financial institutions (who get stuck when owner defaults) pay the price as time goes by for:

- Foundations, walls, roofs, windows, insulation, moisture control, mechanical, electrical systems and fixtures that were **not** designed to work together, were applied by a process that separates rather than integrates
- Products that looked good to builders bid sheet bottom-line, only to deliver headaches and heartaches by not living up to expectation in increasingly shorter and shorter time frames.
- Products that are under-utilized in the context of a "system" part of a "whole house" deliverable.

No single player in the housing industry, to date, possesses the size, the talent, and the resources to alter the momentum. The building industry is hamstrung by conventional thinking that defines the building process as random collections of isolated products or services, from lot selection, to materials, to labor, to mortgage.

A summation of the problem, is that the industry:

- builders,
- architects,
- suppliers, distributors
- manufacturers,
- service providers,
- regulatory bodies

continues to structure and view the home, the process of designing, building and servicing it, **not** as an integrated system, but as a series of single purchase decisions, tasks and transactions, controlled by numerous key gatekeepers.

Meanwhile, the buyer looks holistically at the house (the sum of all its parts):

- Does it work seamlessly together?
- Is it delivering uniformly to my value statement?
- Is the performance as promised and easy to achieve?

The industry is making some inroads. Moving the major part of the construction process into a factory promises a better-organized, more easily controlled approach for manufacturing houses. And progress is being made in overcoming the stereotypes associated with manufactured housing. Unfortunately at this time many of the potential mass-production benefits have not been achieved and products are characterized by few option choices for the consumer.

Also on the plus side, some suppliers/manufacturers are now thinking about the products their product will interface with or become a part of. Cooperative efforts, multi-disciplinary consortiums, and task forces have been started with mixed success. Suppliers have developed some of these team efforts amongst themselves, and some make progress. But few reach the intended benefit as they run into practical problems as they attempt to implement these concepts in the field. Beyond minimal codes or builder preference, there are no commonly accepted standards for plan footprints, room sizes, materials, workmanship, system protocols, installation procedures.

Total systems thinking is the key. The home building industry has suffered from lack of “Total Systems” thinking. For example, virtually none of the new homes built are being mechanically or electrically engineered or fully integrated. Components are not designed to work together. Interfaces are not intuitive - and do not resist incorrect installation. As an analogy, an automobile company would not think of designing an automobile without extensive engineering and interface of a “power group” (engine, transmission, suspension, controls) with the “interior comfort group” (ride, temp control, sound, seating). Vastly more design, producibility analysis, and integration effort goes into a $20,000 car than into a $250,000 house.

Henry Ford industrialized his car because of constraints he had with automation flexibility of that day. He standardized the car frames and built components to adapt to this rigid structural shell. Today we have tools to allow industrialization for differing needs. Today we can build components or modules that can integrate into a flexible structural shell. This is possible as long as the integration of these components is done in a well-defined fashion. Further today we can consider each part of a house from a functional perspective and completely rethink our individual systems approach and change to a “Total Systems” approach.

In the short term we may need standards for improvement in the whole house concept. Moving beyond the short term and looking at the future we look to have advanced industrialization techniques that will allow for mass customization. This mass customization will allow for clients to be able to select options and then through IT systems the components can be custom assembled through automated techniques. Even the option selection process can be automated through better visualization techniques that are themselves integrated into the IT system.

3. SYSTEMS APPROACHES IN USE TODAY

Modular or factory built homes are built entirely indoors. Essentially the materials that would go to the jobsite are brought inside to controlled environments to assemble into modules that are transported to the site and fastened together. Two to five modules can connect together to form the house. Modular and factory built manufacturers position the benefits as

- Stick built in controlled environment
- Reduced on site labor and sub costs
- Quicker cycle time
- Controlled quality and inspection at the plant
- Flexible floor plan options and exterior choices
- Guaranteed pricing and delivery date

All-American Homes is one of the largest (non HUD) modular home manufacturers with plants scattered around the Midwest makes homes are nearly impossible to distinguish from stick built homes.

Manufacturers offer several sizes and styles, but have less choices overall than stickbuilt homes. Some level of machine automation, computerization of materials and scheduling, and more factory-like production practices is typically applied to the production process. Transportation of the modules or the house is a significant cost item and plants typically serve limited geographical areas. Modules are designed to conform to highway limitations. Modules are placed on a site-built foundation with a crane and connected together, usually by factory trained assemblers. Houses can be closed in within a day. Minor exterior finish work and interior finish work are required where seams or joining of modules occurred.

Large capital is required for plants to be built or capacity expanded. Location of plants is critical and can become obsolete in time as housing shifts or logistics and transportation costs become greater. Proximity to housing growth areas, access to highway systems, and work force pool are keys to locating a facility. High concentrations of manufactured home plants are located in the Northeast where the industry got its start. There are large numbers down the Eastern Seaboard and back through Pennsylvania, Ohio, Indiana, Michigan. Large manufacturers include; Westchester, Forest Homes, Avis America, Simplex, Ritz-Craft, Chelsea, Nationwide, All American and Nanticoke Homes.

Modular housing is expected to grow about 25% over the next 8 years. In 1999 approximately 35,000 modular homes were produced, the highest level in 12 years. The entire prefabricated homes (panelized, precut, modular HUD and non-HUD) segment is expected to do about 395,000 units according to the Freedonia Group. Panelized homes will remain the fastest growing portion of the prefabricated segment. North Carolina is the state with the highest consumption of modular homes at just over 2,500 a year. Overall, prefabricated housing of all categories currently represents less than a third of all homes built.

Whole House thinking is occurring in the industry. The need and/or opportunities for whole house approaches to home building are recognized by a number of individuals, companies and organizations in the industry. Some examples of current activities and products are summarized below:

- The Build America Program includes four research consortia of manufacturers and building sciences entities in both the US and Canada. These consortia are looking at a home as a system as related to energy, environment, comfort and indoor air quality. They look at the building envelope and all the components that go into that as a system that must work efficiently together, instead of as individual parts. For example, the Hickory Consortium includes the University of Central Florida, Pella Corporation, Harvard School of Health, the University of Texas and several modular builders with a focus on creation of green home designs and advanced modular homebuilding technologies to produce homes with high quality and efficiency.

- Owens Corning has put many of their products together in a program they call "Systems Thinking", that includes siding, insulation, windows, roofing. Owens Corning states that these components/products are being engineered to work together as a system, optimized for cost, function, and performance.

- DuraKit's Instant House is built from triple corrugated ¾" tre ated cardboard. Walls are layers of flame retardant, water resistant cardboard supported by 3" corner posts. The houses, designed to be used in Third World countries for emergency response or crisis housing needs, pack into 40-foot shipping containers. The houses assemble in one day with three unskilled workers and cost around $13 per square foot. Several models meet most North American Building codes.

- An approach by a South African company named Moladi uses recyclable plastic forms and poured aerated concrete. The homes be "framed out" (forms set, pour completed, forms removed) in about two days. These homes are currently being used to build homes in third world countries.

- Another approach is the Robust Home, which is claimed to be a total building system. It is offered by an alliance of companies who claim that a steel-and-concrete house can be built by 3 men in only 10 days. Although intended for developing countries, it reflects the kind of thinking that might contribute to improvements

- OVE or Optimum Value Engineering, an NAHB Research Center effort, has looked at the framing process as a whole and optimized the use of materials, labor cost, while giving higher quality and improved energy efficiency. OVE reduces framing cost while meeting all the model building codes structural requirements. Documented savings of $500-1000 in material costs, and 3-5% in labor costs, with additional energy savings from 2-5% (reducing monthly operating costs).

- MADE - Marketable, Affordable, Durable, Entry Level Homes - a program put together by HUD, NAHB Research Center, and nationally renowned experts developed a guide. Demonstration houses will be built starting in the summer/fall of 2001 that put into practice an approach that deals with the whole house process. MADE focuses on:
  - Expandability/flexibility,
  - Curb Appeal/Marketability,
  - Affordability
  - Durability

  Key components are flexible open living area, expandable rooms, modest footage, modular dimensions, lot configuration, strategic window usage, OVE framing techniques, stacked bathrooms, porches and overhangs.

- Plumbing manifold/tubing systems by Vanguard and Kitec reduce labor cost by simpler installation than conventional copper pipe and elbow processes. Another company, in Minneapolis, produces bathroom modules that come complete with fixtures and connection points. A self-contained module drops into a plan and is connected to waste, water supply, electrical through several simple connection points. The bathroom module is completely finished and ready for use once connected.

- HUD is funding a “Super Assembler” study aimed at developing a broader category of worker called assembler. The position seen as a growing future need would likely require fewer skills opening potential employment to a broader pool of people. If more and more components come to the site just needing assembly to the whole, new categories of workforce, pay scales, training programs would evolve as well.

- A study - Industrializing the Construction Site - is being performed by Virginia Tech for HUD Policy Development and Research. It is investigating methods for industrializing the home building industry.

4. WHOLE HOUSE SYSTEMS APPROACH

As the name of this paper indicates, the design of the house and the process by which it is built need to be considered expansively. Participants in the roadmapping session in St. Petersburg need to think "outside the box" - outside our current house to what could be achieved using new techniques, materials, and concepts. What are the opportunities for making significant progress toward achieving PATH goals for affordability, durability, energy efficiency, environmental friendliness and safety?

Whole house redesign could take any or a combination of several concepts, all of which have potential for helping future housing. One concept is to fix the structural frame and figure out how to make components fit dimensionally and procedurally into the frame. A second concept is not to focus on the house, but instead on the process - using theories of mass customization, design changeable manufacturing systems that respond to changing needs and automatically determine the manufacturing controls and processes needed to support the frame and components. A third concept is to redesign the house and components for producibility or manufacturability and this concept in fact addresses both the product and the process. And a fourth approach, not necessarily exclusive of any or all of the other three, is to look at integral designs that achieve economies of material and labor by looking at components (e.g. joists and subfloor) as an integrated unit. Each of these requires different approaches, but each can learn from one another and a combination of these concepts may ultimately provide the framework for achieving the very ambitious PATH goals.

Fixing the Structural Frame -- Everything one sees in a house rests on a base dimensional platform. In smaller houses that base tends to calibrate all other components. If the base or "Structural Core" were standardized, it would be possible to determine the dimensions and installation protocols of virtually all the core systems. It then becomes easier to realize economies of scale characteristic of other standard dimension constructs of the Industrial Revolution- most notably the automobile industry.

To meet the challenge of a base dimensional platform, houses must be made simple and repeatable under the "skin", yet infinitely variable in appearance and choices to meet expectation today- Mass Personalization. Like the automobile industry, this product platform strategy for houses:

- Establishes a small number of basic "frames" or "chassis"
- Reduces the number of components through systemic engineering
- Allows for part interchangeability to the fixed platform size
- Utilizes assembly rather than customized fitting
- Provides options, variety, personalization in areas that matter to consumer by varying shapes, exterior styles, interiors and trim levels or details

With frame standardization in the auto industry, came the ability for auto companies to build interchangeable parts which could be "bolted" to the frame in an efficient manner. The approach eliminated custom installation of parts and components by skilled labor. Ford substituted known installation techniques for craft knowledge. By fixing the size and configuration of the frame, Ford had a platform that allowed less skilled workers to install components rather than custom-fit parts, removing the premium paid to craft based workers. Knowledge workers, engineers, and process experts were employed to refine and vastly improve the product.

Mass Customization -- Mass customization is a concept that has been implemented quite well in other industries. This is the use of modern production and information technology to allow mass production of products built to the specifications of the consumer. In the current automotive industry, it allows cars with different interior and exterior colors, different engines and transmissions, and even different models to be assembled on a given line.

Mass customization might be achieved with a variation on panelized, modular or factory built homes, but with a much broader range of options and with the ability to quickly and accurately respond to changes (e.g. the customer suddenly decides they need to have a window in a different place.). The factory would have significantly more automation than is currently implemented in the majority of house or module production facilities. This approach promises to facilitate easier transfer and adoption of manufacturing technologies from other industries (such as automotive), but does have limitations including the need to transport large assemblies and erect/assemble them at the job site.

Mass customization is also being investigated for the jobsite. A HUD sponsored study performed by Beliveau, O'Brien, and Wakefield at Virginia Tech entitled "Industrializing the Construction Site" investigates methods for industrializing the jobsite. This certainly involves implementation of proven manufacturing methods such as Evenflo in home building operations, but also includes implementing information technologies such as Enterprise Resources Planning (ERP). The increasing availability of wireless and web based technology is rapidly enhancing the feasibility of accomplishing jobsite industrializatin. In addition, there are opportunities for application of automated tools or robots. The above-mentioned study briefly discusses use of robots by construction companies in Japan.

Another interesting approach to industrializing the job site is to turn the job site into a factory. According to the above-mentioned study, this approach has been successfully used in Japan for high rise buildings, 20 stories and higher. Variations of this approach may eventually be applicable to low rise residential.

Design for Producibility -- Significant improvements in the cost and durability of a house might be achieved by designing homes for production. We know that other manufacturing sectors expend large efforts to make their products producible in order to reduce labor and materials costs and increase quality. The things they look for include:

- using fewer parts and/or fewer different parts,
- components that are easy to install and that resist incorrect installation,
- integrating functions and components to reduce the amount of labor and/or the number of different kinds of labor required

According to *Design for Cost and Quality: The Robust Design Approach*, by Resit Unal and Edwin B. Dean, NASA's Design for Competitive Advantage website (http://akao.larc.nasa.gov/) -- "The early design phase of a product or process has the greatest impact on life cycle cost and quality. Therefore significant cost savings and improvements in quality can be realized by optimizing product designs." Although it is probably true that most architects design with cost and ease of construction in mind, it is also true that the challenge is to get the home building industry to look at houses in a systematic, robust design, integrated product/process point of view.

Whole House Design and Integration -- The largest opportunities may be realized if the various components, as defined in housing today, can be considered from a functional basis from the whole house system perspective rather than from the performance of individual components or assemblies. As a simple example it might entail moving studs to 24 inch centers which reduces the number of studs and using in-line framing which eliminates the need for doubling the top plate. Another example would be the current view of car design that allows the frame and the skin to work together rather than the old view of build a frame, fit the components and then add the skin. What if floor and wall design were optimized to take advantage of the structural properties of skin (sheathing) as well as the studs or joists? What if HVAC ducts, plumbing and electrical wiring were included in integrated floor modules?

5. WHOLE HOUSE AND PROCESS REDESIGN PORTFOLIO

As mentioned in the Introduction, a March 2000 meeting of builders, manufacturers and researchers resulted in a wide range of technology options and eventually in three high priority technology portfolios, of which one was Whole House and Process Redesign. This portfolio is intended to serve as the foundation and catalyst for further brainstorming and ultimately for development of a vision and a roadmap that defines the activities needed to achieve the vision.

This technology portfolio includes four technology options, -- Modular, Whole House Systems; Whole House Process Redesign; Mechanical System Disentangling/Integration; and Flexible, Adaptable Space. These four options are summarized below and described in slightly more detail in Appendix B.

Modular, Whole House Systems **--**This technology option includes a broad range of ideas and concepts involving modularity, expandability and flexibility. For example, modular designs might include a utility core (includes kitchen, bath, "safe room", laundry) plus bedrooms, living room, dining room and other modules. They might all be manufactured at the site or might be factory-built modules. Modules could be mixed and matched for the local market. Roof trusses might be incorporated for curb appeal, additional mechanical space or storage space. Concepts using no, or minimal, foundations need to be explored. Another approach is to develop designs that provide the opportunity for ready expansion of the interior space over time to offer homebuyers a low first-cost with room to grow with the occupants. This potential for “bonus space” immediately provides added value that can last the lifetime of the building. Other designs that significantly reduce the number of components and complexity of construction may also be considered.

Some European home centers offer customizable, modular mechanical, electrical, and plumbing systems where central utility cores are bordered with kitchens, baths, etc, with bedrooms, living rooms furthest from the core. A good starting point may be to study these systems as well as modular housing in Japan.

Whole House Process Redesign **--** The aim of this concept is to apply a systems integration approach to simplify the number of components and reduce the number of trades involved. By reducing the number of "things", overall performance will be improved and labor dependence reduced. This process redesign can be applied to factory or onsite construction. The use of easy-to-assemble components, such as those that require no separate fasteners (snap-together) is also an aspect of the redesign. This process redesign, linked with ERP (Enterprise Resource Planning), can allow use of unskilled labor to build homes.

Flexible, Adaptable Space **--** Flexible space allows occupants to temporarily adjust spaces in the house by moving/rearranging walls or other dividers. This might be useful for parties, when guests stay overnight, etc. Equally important is that adaptable space allows (relatively) easy adjustment of space usage over the long term as families change, grow or shrink, age, etc. Ideally flexible, adaptable space would make smaller homes more acceptable and would reduce the number of times families would need to change houses.

This technology option could be viewed as an element of the modular, whole house concept described above. However, flexible and adaptable space emphasizes movable interior partitions and walls within the existing envelope. One of the larger challenges to be addressed with moveable walls is in the mechanical systems - HVAC, electrical and plumbing.

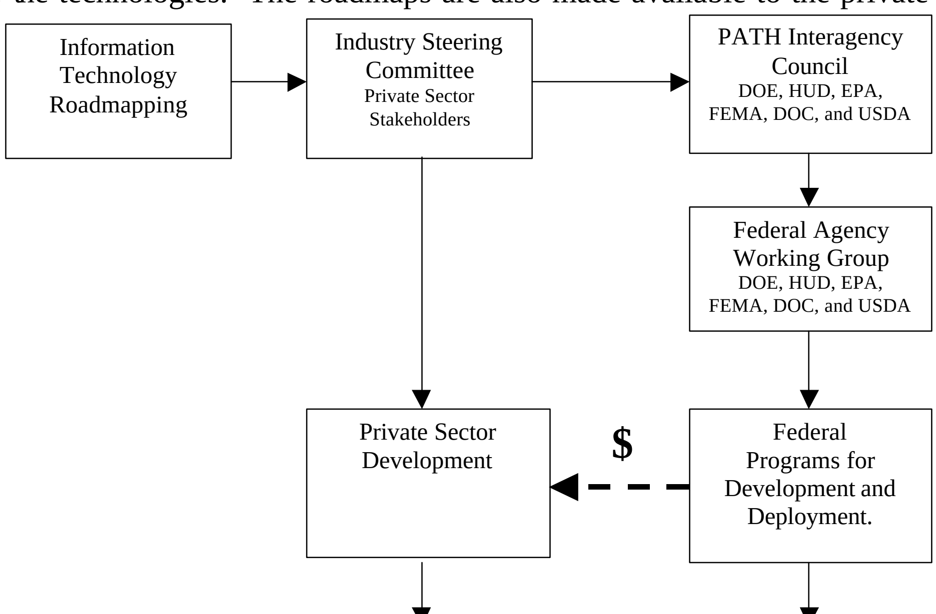
Mechanical System Disentangling/Integration **--** Mechanical systems - plumbing, electrical, communications wiring and HVAC, require significant installation labor and installation and inspection can be significant factors in cycle time. Further, the current approach of installing these systems makes flexible, adaptable space extremely difficult, if not impossible. One concept that needs to be considered for the mechanical systems is the use of vertical and horizontal dedicated service chases for electrical/communications wiring, plumbing, supply and waste and HVAC ducting. Additional concepts that might be considered include plumbing manifolds, prefabricated HVAC ducting and ducting installed in the conditioned spaces, modular and/or surface mounted electrical/communications wiring systems and so forth.

APPENDIX A

PATH Organization, Technology Outreach and Technology Roadmapping

Work is underway on several fronts in pursuit of the PATH goals. Extensive technology outreach activities are ongoing, both over the Internet and in field evaluations or demonstrations around the U.S. At the same time, PATH has a Technology Roadmapping Working Group, which has been laying groundwork for the development and introduction of beneficial new products over the life of the program. The diagram below shows how the technology roadmap information flows. The roadmapping information - time-phased strategies and projects - is approved by the Industry Steering Committee which is comprised of private sector members.

The approved roadmaps are then provided to the public sector via the PATH Interagency Council, which consists of the Assistant Secretaries of participating agencies. High priority items may eventually result in R&D or other types of programs that would accelerate the technologies. The roadmaps are also made available to the private sector,



where companies might decide to, separately or cooperatively, develop products related to or derived from the technology. The end result will drive R&D funding by both the private and public sector.

In addition, four other PATH Working Groups have been organized to focus on the various institutional forces that affect technology adoption and utilization, including (1) finance, (2) labor and quality issues, (3) barriers and insurance, and (4) consumer education. Activities of these PATH Working Groups are also under the general oversight of the Industry Steering Committee are summarized below:

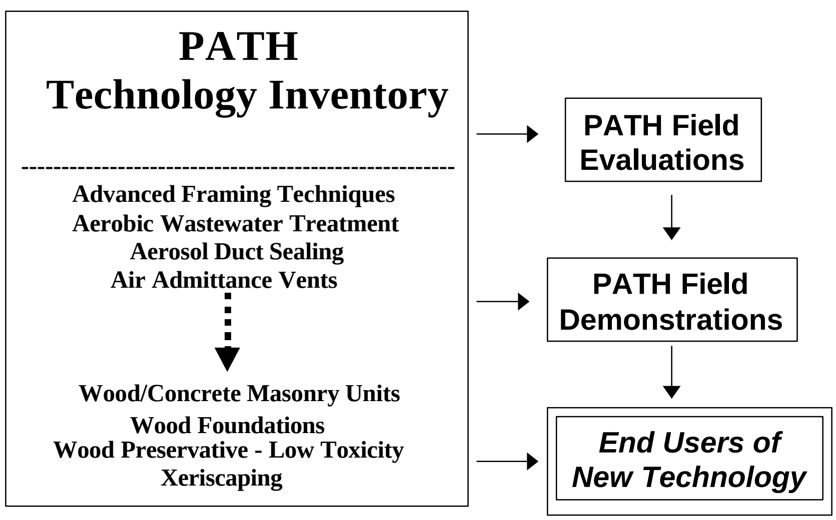
Barriers and Insurance Working Group. This group is investigating ways to help control exposure to liability and translate improved building performance into lower insurance premiums as a consumer incentive.

Consumer Education Working Group. This group is looking at ways to stimulate consumer demand and create market "pull" for PATH technologies.

Labor and Quality Working Group. This group is working to promote quality improvement methods and provide training that will address persistent labor shortages in the construction market. It could potentially play a role by identifying strategies for training construction labor to use information technology and maximizing the quality improvement potential of ERP.

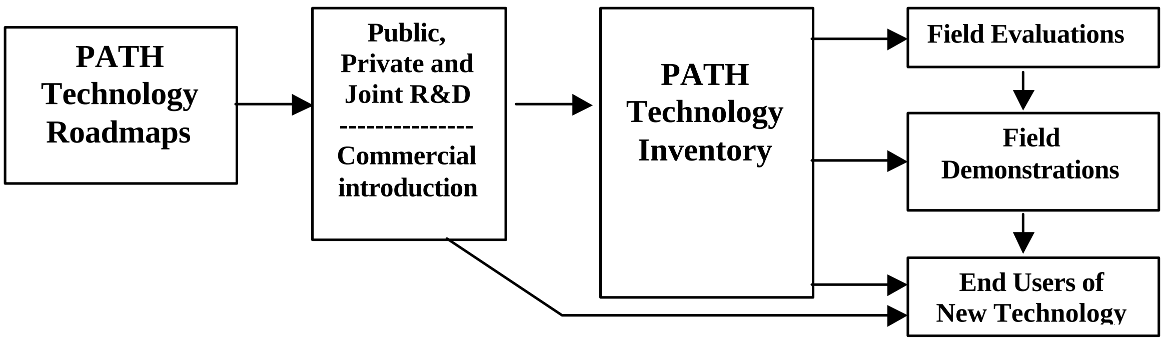
Finance Working Group. This group is working to enhance "energy efficient mortgages" and define similar products offering expanded access to financing or reducing the cost of originating mortgages and other loans.

PATH Technology Outreach. An extensive Technology Inventory with information about new, emerging or underutilized housing technologies was developed early in the program and placed on the Internet at "http://www.nahbrc.org/toolbase/xtech.html". Visitors will find searchable information about the nature and status of more than 150 technologies for housing. Several of these technologies are being more closely studied and reported on as part of PATH Field Evaluations. Others are being used and documented on a larger scale in PATH Demonstration Projects.



Notably lacking from the PATH Technology Inventory are information technologies. The fact that information technologies do not appear in the list is no doubt partly because the technical evaluation team was not looking for such technologies, but may also be symptomatic of the small amount of emphasis the industry has to date placed upon information technologies.

PATH Technology Roadmapping. PATH initiated a process of Technology Roadmapping to complement the technology outreach and help accelerate the development and introduction of new technologies that can achieve progress towards the PATH goals. Roadmapping can be viewed as intended to ensure a future supply of new items for inclusion in the Technology Inventory, and for PATH Field Evaluations and Demonstrations, as shown below. Specific areas for roadmapping will be selected by the Industry Steering Committee, which will review and approve the results.



The roadmapping process began with a two-day brainstorming session in March 2000, where a diverse group of 35 experts reviewed all the PATH goals, then identified and documented a total of 40 "technology options" as candidates for further study. The titles of these options give some idea of their scope and content.

TECHNOLOGY OPTIONS IDENTIFIED DURING MARCH, 2000 PATH BRAINSTORMING

- Advanced Roof Coverings
- Augmented Reality
- Automated Tools
- Connected Home
- Cooling with Night Air
- Distributed Generation - Fuel Cells
- Distributed Generation - PV Solar Cells
- Electronic Control Technology for HVAC
- Enclosed Attic Space
- Enterprise Resource Planning for Home Construction
- *Flexible, Adaptable Space
- Foundation Stave System
- Frost-Protected Shallow Foundations
- Helical (screw) Footings
- Homogeneous Wall Panels
- Improving Safety in Roof Construction
- Indoor Air Quality
- Information Technology for the Approval Process
- Insulating Concrete Forms
- Integrated Wall, Floor and Roof
- Interlocking Roof Sections
- Less-Finished Interiors
- *Mechanical System Disentangling
- Microtechnology
- *Modular/Whole House Systems
- Non-Commercial Information Portal
- Precast Insulated Wall Panels
- Precast Panelized Roof Components
- Prefabricated Ducts
- Radiant Heating
- Roof Sandwich Panels with
- Self-Fitting Membrane Interiors
- Software Integration/Standards
- Sound Isolation
- Targeted Heating and Cooling
- Virtual Inspections
- Water Recycling and Reuse
- *Whole House Process Redesign
- Wireless Communications
- Zero Negative Emissions

*The technology options marked with an asterisk are assigned to the Whole House and Building Process Redesign Technology Portfolio

One-page write-ups of all 40 options in the list can be viewed on-line through the Public Access area at "http://roadmap.nahbrc.org". The brainstorming was followed by an evaluation process in which benefits, risks, market potential and other factors were assessed for each technology option. Based on the results of the participant evaluations, the following three "portfolios" were selected for initial roadmap development:

1. *Information Technology to Accelerate and Streamline Home Building*

2. *Advanced, Panelized-Type Systems*
3. *Whole-House and Building Process Redesign*

Each of these portfolios includes one or more Technology Options that received very high ratings along with other closely related items. Roadmapping task groups being organized under each of these areas will operate concurrently this fall and into the year 2001.

APPENDIX B
WHOLE HOUSE AND BUILDING PROCESS REDESIGN PORTFOLIO

The Whole House and Building Process Redesign Portfolio includes four technology options as follows:

- Modular, whole house systems
- Whole house process redesig**n**
- Flexible, adaptable space
- Mechanical system disentangling/integration

These options resulted from a March 2000 meeting of home builders, manufacturers and researchers in Kansas City (see Appendix A for more details).

Three additional technology options are included as further "thought stimulators" as follows:

- Integrated wall, floor and roof systems
- Roof sandwich panels with utilities
- Prefab ducts in conditioned space

Modular/Whole House Systems

Technology Description

Description: Utility core (includes kitchen, bath, safe room, laundry …) + bedrooms + living room + dining room, etc. all manufactured at site. Mix and match for market. Roof trusses incorporated for curb appeal/additional mechanical space/storage space. No or minimal foundation. Designs that provide the opportunity for ready expansion of the interior space over time offer homebuyers a low first-cost with room to grow with the occupants. This potential for "bonus space" immediately provides added value that can last the lifetime of the building.

Current Status - This system is being used in commercial (motel/hotel/jail) mostly precast. Similar concepts are used in mobile homes. It was tried in the late 1960's using precast concrete segments and was abandoned for commercial reasons. Some European home centers offer customizable, modular mechanical/electrical/plumbing systems where central utility cores are bordered with kitchens, baths, etc, with bedrooms, living rooms furthest from the core.

Benefits

Affordability:	High - Minimum site labor and flexible space. Could even increase or reduce size of house over time, Can be flexible enough to have unique looking housing.
Energy/Environment:	Medium - Significantly less jobsite waste. Also, there will be less site disturbance due to component design and off site manufacturing. This will be somewhat offset by shipping requirements of the larger segments. : Economizes use of materials and methods.
Durability:	High - Full control on energy/sound/durability/safety since the segments will be fabricated under stricter quality control.
Safety:	Medium – The increase in worker safety through factory production will be offset due to crames setting segments into place.

Technology Development Risks and Barriers

- Significant design, development and testing required to achieve systems that are aesthetically pleasing, low cost to manufacture the modules, and require minimal skilled labor to assemble on the site.
- High capitalization will ultimately be necessary to incorporate modern manufacturing techniques.
- The cost/benefit ratio may be difficult to achieve.

Other Risks and Barriers

- Consumer acceptance - aesthetics/curb appeal.
- Acceptance by trades and training of trades/labor.
- Transportation (size/weight/damage)
- Negative professional and public perception realized from past failures.
- Perceived as "low cost/low quality," relating to current infrastructure of mobile and modular design.
- Building code compliance (e.g., fire, etc.) of such a "slide-in" concept may initially become costly, drawn out, and thereby difficult to deploy.

Other Risks and Barriers

Whole House Process Redesign

Technology Description

Description: The aim of this concept is apply a systems approach to integrate to simplify the number of components and trades involved. By reducing the number of "things", overall performance will be improved and labor dependence reduced. This process redesign can be applied to factory or onsite construction. The use of easy-to-assemble components, such as those that require no separate fasteners (snap-together) is also an aspect of the redesign. This process redesign, linked with ERP (Enterprise Resource Planning), can allow use of unskilled labor to build homes.

Suggested Procedure:

- Start with functional definition.
- Move to integrated process.
- Move to new tools, possibly robot installation processes.
- Redefine crafts labor requirement.

Current Status: This is a major product and process design delivery procedure that is in the early stages of evolution in manufactured housing. The beneficial aspects of this design and evolution will migrate to site built housing as the benefits are realized and proven in the controlled factory settings.

Benefits

The main benefits reside in the process of functionally evaluating every item and step in the design and production of housing. The long term simplification of automation and reduction of trade person expertise required will allow residences to be constructed more economically.

Affordability	Medium – the main benefit of housing and process redesign is to simplify construction, reduce reliance on worker knowledge.
Energy/Environment	Low- Simplification could allow less material waste but minimal energy impact would occur
Durability	Medium – by reducing the number of components and interfaces the probability for infiltration will be reduced.
Safety	Medium – The reduction of labor will reduce the duration of construction and thereby reduce the probability for injury.

Technology Development Risks and Barriers

Long term effort to look at how to simplify.
New tools or processes need to be integrated.

Other Risks and Barriers

Momentum, history, hard-headedness.
An additional inertia will be created in eliminating the reliance on skilled trade people the codes and permitting processes are set up not only to encourage but to require work be completed by licensed trades people.

Estimated Time to Develop and Deploy

Multi phase: the first phase of process design is under way in the manufacturing domain. The second phase of migration and component integration into the site built domain will take 5 to 20 years.

Flexible, Adaptable Space

Technology Description

Flexibility -- An ability to temporarily adjust spatial use possibly requiring minor portability of spatially defining elements (e.g. walls)
Adaptability -- An ability to permanently adjust spatial use, possibly requiring portability or physical modification of spatially defining elements.

Spaces can be visually defined with stand-alone fireplaces, bookcases, bulkheads or any number of other architectural elements. Increased use of such devices can reduce the amount of materials used in homes while providing more flexible use of the spaces. Portable screens, curtains, accordion doors, and operable partitions are useful in temporarily adjusting the volume of a space for particular uses. Japanese structures have used ganged, pocketed privacy screens (like sliding doors) that facilitate the perception of almost any degree of security or openness.

The affordable availability of roof trusses that can provide wide, unsupported spans allow implementation of moveable walls/partitions, provided that requirements for utilities can be solved.

Benefits

Affordability	Little, no, or negative effect on first cost, but potentially lower life cycle cost.
Energy/Environment	No energy effect, but reduced material consumption over the life of the house.
Durability	Medium to High - Less demolition and repair demands over the life-cycle of the structure.
Safety	High -- Lowered need for exposure to dangerous demolition and repair tools/techniques.

Technology Development Risks and Barriers

- Services: Mechanical / Plumbing / Electrical (MPE) service technology is improving but needs further development to seamlessly accommodate full flexibility (e.g., relocation of toilet).
- Spatial Compression: Unlikely to be accepted by society, however, the prime precepts of the approach remain usefully incorporated into housing stock.
- Design: Design is difficult! New and improving visualization tools will aid design exploration into this area, yet the creativeness of the designer remains crucial to the success of the endeavor.
- Implementation: Historical evidence (e.g., passive solar) exists to conclude that non-automatic, manually controlled elements are infrequently operated, thus thwarting the multi-flexible character of the elements.

Other Risks and Barriers
Realtors and remodelers may resist.

Mechanical System Disentangling

Technology Description

"Disentangling the mechanical systems that are distributed through the structure of the house is a part "Whole House Design". process and a part system technology. The system technologies would include vertical and horizontal dedicated service chases for electrical, communications wiring, plumbing, supply and waste and HVAC ducting.

Current Status: Chases are not used in residential applications today, although they are common in commercial buildings.

Benefits

Affordability	If true design integration is achieved, systems installation would be quicker, friction would be reduced and costs reduced through reduced materials and labor.
Energy/Environment	Increased comfort to resident and potential energy efficiency, but not a driver.
Durability	Technology obsolescence is reduced/eliminated; and service/maintenance/upgrade is easily facilitated via accessible chases.
Safety	No safety benefits are evident.

Technology Development Risks and Barriers

No major technology development risks; but barrier in who is the supplier/producer of the chase systems/components.

Other Risks and Barriers

Lack of clear understanding of the benefits by the builder and lack of incentive/initiative to integrate the trades into the process/solution.

Also a potential hurdle is lack of whole house design and integration process/service for the builder.

Integration of all of these mechanical subsystems into one system, and potentially one chase, will probably have a number of implications for codes - possible modifications or reinterpretations.

Which trade contractor installs the system - plumber, electrician, HVAC?

Roof Sandwich Panels with Utilities

Technology Description

Description: An integrated structural roof panel product with embedded photovoltaic circuitry, hydronic piping, waterproof exterior surface/roof covering, insulation, and textured interior surface.

Status: Currently most roofs are assembled in place, with structural members, sheathing, building felt, shingles, insulation, venting and interior surfaces built on site by multiple trades.

Benefits

Affordability:	Moderate benefits in the form of reduced cycle time, simplified mechanical installation with hydronic piping installed off-site, and easy opportunity to finish attic space.
Energy/Environment:	PV circuitry would have clear benefits if it could be incorporated without driving cost to unacceptable levels, although this is a long-term prospect at best. Some types of insulation used in panel products outperform mineral fiber materials on an inch-for-inch basis, so assembly R-value could be improved over typical cathedral ceilings built without oversized framing or trusses.
Durability:	Shingle blow-offs could be eliminated by eliminating shingles, and the lifetime of this assembly could easily reach 50 years. Factory quality control in fastener installation could improve roof diaphragm action in high winds.
Safety:	Minimizes worker exposure to the hazards of constructing roofs in-place.

Technology Development Risks and Barriers

Structural design issues vary by location but would need to be addressed. Extremely durable gaskets or joint treatments between adjacent panels and at the roof ridge are required. It is not clear how to produce the panels on-site or close by without sacrificing potential economies of scale and quality control. A flexible approach to production is needed for the system to work with the complex rooflines found in many new homes. An interior surface that withstands some flex during transportation and installation without cracking or requiring extensive refinishing is necessary.

Other Risks and Barriers

Various code issues arise concerning roof assembly ventilation and non-standard roof covering systems. Problems in the distribution chain if producers or middlemen need to stock many variations of the basic panel. Logistical issues with transportation of very long or wide panels limit opportunities for centralized production and scale economies. There is limited value of hydronic piping in markets where central air conditioning is standard.

Integrated Wall, Floor and Roof Systems

Technology Description

This is an open or closed wall, floor, roof system that can be put together in a factory or in a structured, on-site process. This system can incorporate several functional systems including: thermal inertia, r-factor, electrical (lighting) distribution, cooling, heating, solar collector, water, sanitary sewer, acoustics, surface aesthetics, and human contact with the environment. The current systems include precast (one to multiple layers), tilt-up (one to multiple layers), SIPS, ICF, engineered wood, etc.). Material choices include: wood, expanded polystyrene, polyurethane, concrete, hydrated concrete, and others.

Also included in this concept a wall panel process that prefinishing wall panels off site and delivering to the house JIT. The process would allow the finish to be customized to each buyer/house and delivered to the site to eliminate several of the trade integration issues currently experienced on the job site.

A specific technology showing good potential is precast or composite panels with carbon fiber reinforcement. Such panels are low cost and lightweight. When used in combination with post and beam construction, they provide extremely affordable housing solutions in certain climates. Similar panels when combined with insulation and interior finish promise to be affordable solutions in any climate.

With the proper R&D most of those familiar with the product feel that the carbon could be developed to act as both the reinforcement and radiant heat element when used in the inside wythe (room side of the sandwich insulated panel) European company has already developed a very lightweight cellulose filled "precast" that can be cut, drilled, sanded, etc. with standard tools. With this on the inside combined with a sandwich insulation core and a precast structural outer wythe the panel may be structurally capable as a "stand-alone" building component.- no post and beams, etc.

Current Status: "Unfinished or partially finished panels such as SIPs and precast, tilt-up are being used, although not yet widely. The use of totally finished panels, custom made by "mass customization" in the factory and delivered to the job site is not widely used, if at all.

Benefits

Affordability	High, depending on the market and region and number of systems integrated. Panels reduce redundancies and part counts while shorter contractor cycle through concurrent activities negating on site sequence delays and interface failure
Energy/Environment	High, depending on the thermal inertia and r-factor
Durability	Excellent, Less movement of materials creates tighter buildings that allow less air and water infiltration therby increasing the material natural service lives.
Safety	Excellent, Single lift of each panel reduces unstructured labor doing high work on site or off site labor is more managed and will provide production quality improvement

Technology Development Risks and Barriers

- Research is needed to find or develop the appropriate materials.
- Education in building science and systems integration is weak.
- The technological problems are found in the economical structural attachment.

Other Risks and Barriers

- Momentum, history, hard-headedness
- There is bias by architects, real-estate agents, etc. about panelized construction.
- Custom building is perceived as a stick-framing process only.

- Low level of consumer awareness.
- Transportation cost of panels.
- Panelization has been around for a long time, but is not widely accepted.

Prefab Ducts in Conditioned-Space Building Cavities

Technology Description

Prefabricated duct systems offer the potential to improve system quality and eliminate installation time spent on site. Ducts run within conditioned space offer greater delivery efficiency. A design approach that combines these two goals will focus on prefabricating duct runs prior to site installation and using these ducts within the conditioned spaces of the building. These spaces include basements, framing cavities like coffered ceilings, and even decorative features like columns.

The prefabricated duct runs could be formed from traditional sheet metal or other materials that minimize flow resistance. Since many prefabricated chases will be limited in space, duct materials that minimize resistance to flow should be considered (i.e. PVC). Runs should be designed to maximize flow and minimize leakage. Prefabricated ducts intended for stick-built projects should limit their lengths to sizes that can be realistically transported to the site and installed. In a modular housing environment, prefab ducts can be formed and installed "on site" in the plant before units are shipped.

Benefits

Affordability:	: Improved duct delivery efficiency will result in lower HVAC costs and require less energy. This efficiency improvement can be gained from reducing leakage and improving flow characteristics.
Energy/Environment:	Simple and/or redundant house plans that contain long, straight cavities for ducts may be less expensive to install using a prefab system. Modular housing offers even better savings potential, as do regions with higher labor rates.
Durability:	Prefab duct systems should last indefinitely as do those of normal construction now. The sealing of joints should be superior for prefab systems since they are applied in a controlled environment.
Safety:	Prefab ducts may reduce accidents on job sites as less cutting, bending, time on ladders, etc… will take place in the field.

Technology Development Risks and Barriers

- Research on easy to cut, easy to fasten materials that are adequately fire retardant, low cost and environmentally friendly may be appropriate.
- If alternative materials like PVC or ductboard are use there will be code compliance issues that will require research and testing and working with the code bodies.

Other Risks and Barriers

Builders may resist a significant change to their normal procedures. For this technology to succeed, the builder and HVAC fabricator will need to coordinate earlier in the construction cycle than is typical. An HVAC supplier/fabricator will also have to be identified by builders and obtain enough volume to keep a shop going. Outside of the modular industry this will be difficult for an emerging service.