PATH
PARTNERSHIP FOR ADVANCING TECHNOLOGY IN HOUSING

TECHNOLOGY ROADMAP: WHOLE HOUSE AND BUILDING PROCESS REDESIGN

2003 Progress Report

U.S. Department of Housing and Urban Development
Office of Policy Development and Research

PATH (Partnership for Advancing Technology in Housing) is a private/public effort to develop, demonstrate, and gain widespread market acceptance for the "Next Generation" of American housing. Through the use of new or innovative technologies, the goal of PATH is to improve quality, durability, environmental efficiency, and affordability of tomorrow's homes. PATH is managed and supported by the U.S. Department of Housing and Urban Development (HUD). In addition, other federal agencies that engage in housing research and technology development are PATH Partners, including the Departments of Energy, Commerce, and Agriculture, as well as the Environmental Protection Agency (EPA) and the Federal Emergency Management Agency (FEMA). State and local governments and other participants from the public sector are also partners in PATH. Product manufacturers, home builders, insurance companies, and lenders represent private industry in the PATH Partnership.

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Prepared for:

U.S. Department of Housing and Urban Development
Office of Policy Development and Research
Washington, D.C.

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May 2004

About Newport Partners LLC

This report was prepared by Newport Partners LLC, a small, women-owned and managed business. Newport Partners LLC provides analytical and technical services to clients in both the manufacturing and public sectors, with an emphasis on building technology and the introduction of innovative products.

Acknowledgement

Involved in the production of this publication was Steven Winter Associates, Inc., a leading architectural research and consulting firm based in Norwalk, Connecticut. Newport Partners LLC would also like to recognize the following individuals for their contributions:

- Barry Rosengarten, Rosengarten Enterprises, Inc.
- Bob Oswald, Green Building Team
- Bob Schmitt, Bob Schmitt Homes, Inc.
- Chuck Koon, C. Corp. Companies
- David Cohen, Cohen Brothers
- David Gunia, K. Hovnanian Companies
- Emanuel Levy, Manufactured Housing Research Alliance
- John Wesley Miller, J.W. Miller Companies
- Ron Wakefield, Virginia Polytechnic and State University
- Stephen Kendall, Ball State University
- Tedd Benson, Bensonwood Homes
- John Heilstedt, Elkay Companies
- Buddy Hughes, Buddy Hughes Construction
- Dana Bres, Dept. of Housing and Urban Development
- Carlos Martin, Arizona State University

Disclaimer

Preface

This interim report, *Whole House and Building Process Redesign Roadmap*, documents progress in the development of a technology roadmap that addresses the "whole house" perspective on home building, and the entirety of the home building process. Roadmap development was initiated in 2001, and a status report on year one activities was published in 2002. This interim roadmap report incorporates the results of activities and work performed since early 2002.

The subject matter defined in the Year One progress report for this roadmap is broad, loosely defined and largely conceptual, resting on broad mandates such as "Change the Home Building Paradigm." This may be appropriate or even necessary at early stages in the process, but it defers the difficult task of creating a final, operational roadmap from the first year's report. Thus, it has been challenging to balance the desire for an overarching vision and lofty goals with the practical realities of a large and diverse industry that is reluctant to change, and a small annual budget with which to bring about change. To solve this dilemma we have gathered input from a wide range of interests in creating this document, which is part "roadmap" and part strategy for working towards a comprehensive, integrated whole house roadmap that is relevant to the segments of the industry which produce industrialized housing, both modular and manufactured, as well as to site built housing. Our priority was to produce a useful document delineating necessary activities and projects by which the industry could measure progress rather than to put out a final document resting on unachievable or overly-broad strategies.

New technologies and processes as described in this document offer promise to the building industry in many ways. The adoption of innovative business practices from other industries and the integration of various subsystems of the home into a systems-based approach will offer further improvements in durability, cost effectiveness, and cycle time. We invite manufacturers, builders, trade contractors, researchers, and others to examine this roadmap, request information on ongoing or potential research projects, and actively participate as it is further expanded and implemented.

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PATH PROGRAM GOALS

The Partnership for Advancing Technology in Housing (PATH) encourages the use of technology to improve the affordability and value of new and existing homes. Through public and private efforts in technology research, information dissemination, and barrier analysis, PATH is adding value to seven of the nation's key housing attributes:

- affordability
- energy efficiency
- environmental impact
- quality
- durability and maintenance
- hazard mitigation
- safety

As such, four overarching goals have been established that all bear on those attributes:

To remove barriers and facilitate technology development and adoption

PATH will investigate the barriers, including regulatory barriers, that impede innovation, and will actively propose and develop programs to overcome those barriers. This work will guide the other goals and efforts.

To improve technology transfer, development, and adoption through information dissemination

PATH will coordinate dissemination of innovation information directed to the housing industry and consumers.

To advance housing technologies research and foster development of new technology

PATH will support "background" and applied research as well as technology development activities in the housing industry. This research will be complemented by short-term and long-term assessments of specific technologies that are on the market.

To support the program through appropriate management and resource allocations

Partners in the PATH program - U.S. Department of Housing and Urban Development, Department of Energy, Environmental Protection Agency, Department of Agriculture, Department of Commerce, Federal Emergency Management Agency, home builders, researchers, and manufacturers of building materials and products - have long recognized the importance of injecting current and emerging technologies into the home building process. The PATH program has identified many of the relevant technologies and has facilitated implementation of research, pilot, demonstration, and evaluation projects across the United States. In addition, PATH program partners recognize the importance of planning research and setting priorities for technology development that will enable the housing industry to work toward the PATH mission. This priority setting is known as "Roadmapping."

ROADMAPPING PROCESS

The objective of PATH roadmapping is to identify technological research in home building to serve as a guide for investments by government and industry. The PATH Industry Committee (IC), comprised of builders and manufacturers of building products and materials, oversees the development of technology roadmaps for the site built housing industry.

As the premier planning activity for PATH, the roadmaps dictate the main areas for research and development in PATH's research portfolio (which includes background, applied, and development activities) as well as provide the home building industry with a strategic plan for future technology development. Through this process, new technologies and additional research work will be generated as the roadmaps are implemented.

The IC initiated the overall roadmapping process during early 2000. A group of 40 builders, material and product suppliers, academicians, researchers, and other stakeholders identified and prioritized technologies that hold promise in achieving PATH's goals. The IC then grouped the technologies with the greatest potential benefits into broad portfolios. These portfolios represent three initial technology roadmaps for new home construction. At about the same time, additional roadmaps were initiated by the manufactured housing industry and the remodeling industry to address PATH goals and objectives relevant to these sectors of the home building industry. The result is the following five roadmapping activities currently in different stages of development:

1. Information Technology to Accelerate and Streamline Home Building
2. Whole House and Building Process Redesign
3. Energy Efficiency in Existing Homes
4. Technology Roadmapping for Manufactured Housing, and
5. Advanced Panelized Construction

Each of the roadmaps has a separate report. This report deals specifically with Whole House and Building Process Redesign.

Since late 2001, a series of activities and meetings of participants have been held to set the framework for the development of the *Whole House and Building Process Redesign Roadmap*. These activities resulted in a Year 1 Progress Report in June 2002. A set of short-term priorities was also established, several of which PATH has turned into R&D projects expected to commence in the fall of 2003.

In the spring of 2003, subsequent activities were conducted to get broad input from builders and others in the industry. This report is the result of the activities to date and guidance for future projects that need to be undertaken. It also contains activities that need to be undertaken to complete a roadmap on this topic.

Meeting of Technology Roadmapping Work Group

VISION

The vision stated in the 2002 progress report is shown in the text box.

The objective of this document is to lay out the research and technology development and other activities needed to transform this vision into reality. The challenge is to keep the vision elegantly stated in the 2002 report and balance it with the reality of limited resources and meaningful progress. The end result must be achievable if the prescribed Research and Development program is undertaken.

2002 Roadmap Vision

Simply stated, the vision for this Roadmap, ***Whole House and Building Process Redesign****, is to "Build Better Homes Faster and at Lower Cost." The vision continues:*

By 2010, home design and construction is efficient, predictable, and controllable with a median cycle time of 20 working days from groundbreaking to occupancy with resulting cost savings that make homeownership available to 90 percent of the population.

Homebuyers are pleased with their purchases because their homes have many of the benefits of custom houses yet cost less, have fewer defects, are more durable, and have lower operating and maintenance costs than the equivalent houses of 2001.

Builders and subcontractors maintain or improve margins by reducing costs and selling more homes.

This will be achieved through improving the whole house design and the manner in which a house is constructed using new and innovative products, systems, processes, and education.

THE SYSTEMS APPROACH

The topic of whole-house design is closely linked to the application of "systems engineering" principles. The systems engineering approach starts from the often-repeated observation that "the house is a system" in which specific products, materials and construction methods that may involve just one part of the house actually can have impacts throughout the house. The theory is that understanding these impacts and the interactions across parts of the house, and incorporating this knowledge in the design process, can avoid unintended negative interactions. Further, it can also provide new opportunities to "optimize" by capitalizing on synergies or positive interactions to improve performance without increasing cost, it can reduce cost without sacrificing performance, or it can improve performance and reduce cost simultaneously.

Perhaps the best example of the potential offered by systems engineering is the interaction between thermal performance of the building envelope and sizing of mechanical equipment, particularly air conditioning equipment. Tightening the shell, adding insulation and upgrading windows cut heat loss and heat gain. The direct effect is to reduce the need for space conditioning and save energy. The "systems" benefit is that by cutting the load they also allow installing a smaller, less expensive cooling system without sacrificing the ability to maintain comfort.

It is true that the house is a system. More properly the house is a system of systems, including a structural system, envelope system, mechanical system, electrical system, plumbing system, and many others. Each of these systems may include sub-systems which are systems in their own right. It is also true that these systems interact with one another, sometimes in very complicated ways, to determine the performance of the end product. Unfortunately, the number of parts and pieces in a house is exceedingly large, and the number of potential interactions to be considered is far larger still. And while some of these interactions are undoubtedly very important, some may be trivial or even inconsequential. It is important to focus on the larger interactions.

The systems philosophy is often presented as new or revolutionary, but there is reason to believe that designers have been doing informal, simplified systems analysis and optimization all along, sometimes under names such as "value engineering" and generally limited to very well understood, potentially large interactions. The challenge of a more comprehensive approach is that it requires a very large body of knowledge to execute. "Optimization" across systems requires a set of performance metrics for each system, a mathematical understanding of their relationships, and ideally the ability to translate these performance metrics into economic terms. If the approach is so complex that only a few people can implement it, then its ability to impact the industry is very small. Considerable research is still needed to fill existing knowledge gaps, and to develop manageable, simplified procedures for applying systems approaches throughout the design process. Furthermore, this approach must be compatible with a world of specialized product manufacturers and construction trades. In other words, the system solutions developed through whole-house design approaches must ultimately be reduced to parts and pieces that can be assembled, maintained and repaired by persons who know little or nothing of the underlying analytical methods.

SITUATION TODAY

The roadmap status report of June 2002 identifies several important points regarding the status of "whole house, systems thinking" in the home building industry. These include:

- Homebuyers want more customization and personalization in their homes than ever before. This is somewhat in opposition to some of the fundamentals of industrialization and productivity improvement to minimize variability. Industry refers to this as a need for mass customization.

- Homes are becoming less affordable while the perception is that they are less durable than older homes. The challenge of building affordable and durable homes opens the opportunity for systems thinking in the design and construction of homes.

- The homebuilding industry is a fragmented industry with as many as 99,000 contractors building 1.2 million units each year. These builders rely for the most part on subcontracted labor and a wide range of suppliers, resulting in a complex management process. Furthermore, this structure works against the introduction of new technologies and processes.

- A few innovative builders have adopted productivity improvements borrowed mostly from the manufacturing sector. However, the vast majority rely on processes and systems that have been around for decades. Likewise, the number of builders who embrace a systems approach is minimal.

- Several current examples of whole-house approaches exist such as the DoE Building America Program, Optimum Value Engineering, various kit home systems, and various research programs.

BARRIERS / CHALLENGES

The reasons whole house or systems approaches have not been applied in the home building market are numerous. Issues include:

- The fragmented nature of the industry is not conducive to innovation. Small builders simply can't afford to take large risks.
- Aesthetics and function drive the design of homes. Durability, energy efficiency, or systems design are only occasionally considered.
- The regulatory process does not encourage innovation, and in many cases, imposes a burden or penalty on the innovator.
- Consumer perceptions hamper acceptance of some new technologies. For example, faster construction or factory-built components often are viewed as inferior.
- The management challenge of home building in the current environment limits the builder's willingness to innovate. In many cases, large parts of the decision making or control rest with the subcontractor, not the builder.
- The labor pool is not sufficiently trained, further increasing the challenge for innovators. Like builders, many laborers and subcontractors are also resistant to change.

SIGNIFICANT DEVELOPMENTS IN THIS REPORT

The original whole house roadmap group identified a series of potential strategies for increasing whole-house and systems thinking into the design and construction of homes. The next step was to look further into these suggested strategies and refine them accordingly. The process by which these revisions were made include a series of electronic communications, and telephone and in-person interviews. Efforts were made to broaden the input and, in fact, this document represents a wide range of inputs including: universities, builders, remodelers, product manufacturers (both within and outside the industry), trade associations, local governments, non-profits, and others. Based on this input the following updates to the 2002 Progress report are provided.

Manage the Change Process and ***Change the Home Building Paradigm: Create an Environment that Facilitates Systems Solutions***, cut across all aspects of society. They represent institutional changes that need to occur if we really want to make it easier to innovate.

Although recognized as important to housing innovation as a whole, additional review by the roadmap participants suggests these are overarching issues appropriate to PATH activities generally, but not as specific strategies under this (or any other) roadmap. The sheer size of these issues and the difficulty in addressing them within the scope of discrete PATH roadmaps, budget constraints, and a 2010 time frame, suggests they need to be largely removed as priority strategies but kept within the framework of PATH and within all the roadmapping activities.

The challenge is to keep the context of the original strategy but reduce it to an initiative obtainable within the program. Participants recommended a strategy to highlight or demonstrate examples of successful alliances in the building industry and other industries that addresses systems approaches to design and construction. The group's thinking was that these two strategies are closely related and that efforts to implement a systems approach would also have to include management of the change process.

The 2002 progress report contained a strategy titled **Apply Robotic Automation Technology to**

the Process. We did preliminary research to better define what the state of the art was in regards to robotics and presented the issue for discussion to a wide range of participants. The research revealed that there are few robots to be found in the construction sector as a whole much less in housing. The type of image that comes to mind when we envision robots or a mobile smart device taking the place of a human in some activity is not present on a construction site. However, ever since machines came under computer control we have had various levels of automation and we can expect that to continue and even accelerate. Mechanical devices under computer control can readily be found in the manufacturing environment of products that go into housing, and in the case of modular or manufactured housing to a lesser extent.

We have identified a couple of uses of robots in high-rise construction in Japan. Shown here are two:

Courtesy: Takenaka Corporation

Concrete Floor Finishing Robot

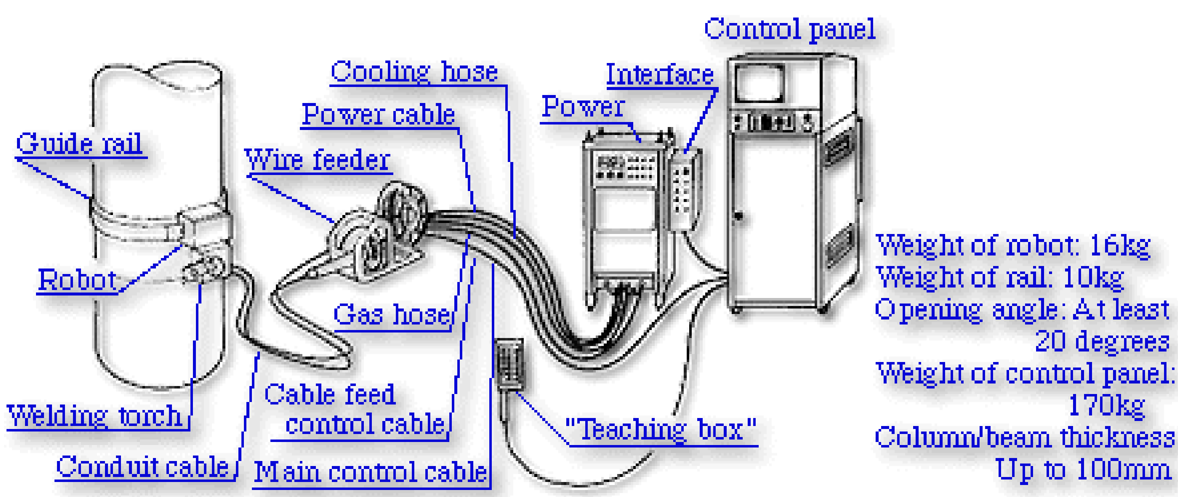

Diagram of a Steel Welding Robot

Courtesy: Takenaka Corporation

Although the increased development of a systematized approach to construction using more prefabricated components delivered to the site has advanced the degree of automation now possible, the traditional reasons that innovation comes slowly to housing clearly apply to robotics. In addition, consider:

- Robotics succeed with repetitious tasks in controlled environments. In housing, one has to cope with an almost unique set of circumstances on each project and site.
- Robotics fit into a well-organized manufacturing system. The housing construction site is dynamic in nature with the hazards and difficulties presented by temporary workers, weather, and the need to accommodate multiple activities.
- Robotics for construction still aren't developed and currently have questionable application.

Over 90% of the robotics applications in the United States are for materials handling, dispensing/coating applications, and spot or arc welding in factory settings. Products displayed at the recently held 2003 Robots and Vision Show demonstrate that robots continue to be concentrated on factory and manufacturing applications and the technology improvements are primarily incremental.

Roadmap participants were asked for specific input on the application of robotics to the home building process. The consensus was that this activity is interesting but premature. Even product manufacturers within their much more controlled environments had little interest in current or future applications. However, it was recognized that a technology program such as PATH must always look to advance the state of the art and that this activity should be reconsidered in the future with the benefit of research on potential applications.

Move More of the Home Building Process into the Factory, focuses on modular and manufactured housing. Many participants commented that factory built homes could hold the solution to many of today's labor, safety and other problems. On the other hand, they also believe this strategy will require commitment from the manufactured housing industry and should be part of a jointly developed roadmap with builder input. Initial discussions support joint development of this strategy. No further development of the topic is contained in this document.

Create Better Living Environments, is a new strategy. During the review process, participants frequently cited the need to focus on systems or whole-building approaches to make homes a better place to live. Examples include improving the health, comfort, and functional performance of the home. This strategy recognizes that people desire different attributes and functions in houses at different life stages. A preliminary effort at defining a research agenda that allows for more user/ inhabitant decisions and allows a house to be easily changed is part of this strategy.

ROADMAP

OVERVIEW

One of the challenges of this particular roadmap is to delineate what is included under the broad heading of *Whole House and Building Process Redesign*. Clearly, “whole house” can mean anything and everything within the building unit from the roof to the foundation, and the building process could include regulatory issues, administration, and management within the building company. The first step in this process was to establish a definition that could be used as a framework for the process and provide for a more focused product.

The idea of "whole house design" is attractive at both an intellectual level and a practical level of improving the house delivered to the customer. The house is made up of many complex systems that interact to produce the final product. Thus, for purposes of this roadmap the definition includes changes to the design and construction of homes that improve quality and performance through one or more of the following:

- 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.

The current version of the Roadmap does not address each of these criteria in a comprehensive manner. The topic is still too broad to enable a comprehensive approach. This document does include the key strategies that the participants believe are currently important to the industry. The definition above will allow the Roadmap to expand over time as new opportunities or priorities are identified.

The specific strategies recommended are the most clearly defined as well as the highest priorities. These strategies should be the starting point for PATH and industry in implementing the *Whole House and Building Process Redesign Roadmap*.

1 INFLUENCE THE CHANGE PROCESS:
Encourage and Document Successful Systems Building Alliances

The barriers to systems-oriented design and construction of homes are closely related to the fragmented nature of the industry and its resistance to change or risk. This fragmentation results in few resources for research or investigation of innovations. Even larger production builders have limited resources compared to a GM or Ford who follow a systems approach in other industries.

Application of a systems approach to design and construction would require change across a wide spectrum of the building process. For example, designers cannot simply decide to adopt a systems approach without buy-in from the builders and trade contractors. Likewise, these groups must be able to secure endorsement and participation of suppliers and regulators. Managing these groups and the process will be the challenge that must be met if systems thinking is to truly be successful.

To address these strategies is no easy task for the industry nor is it something a program such as PATH could reasonably expect to solve alone. It basically requires changing the way people think across disciplines that have historically had little or adversarial interaction with each other.

The working group comments suggest that PATH has a role in pushing systems thinking to the forefront of the industry and helping to facilitate its adoption. Primarily, this role should be through dissemination of success stories and small-scale demonstrations. The results would show how an alliance or group could indeed "manage the change process" to enable systems-based design and construction. The activities to address this are shown in the graph and as follows:

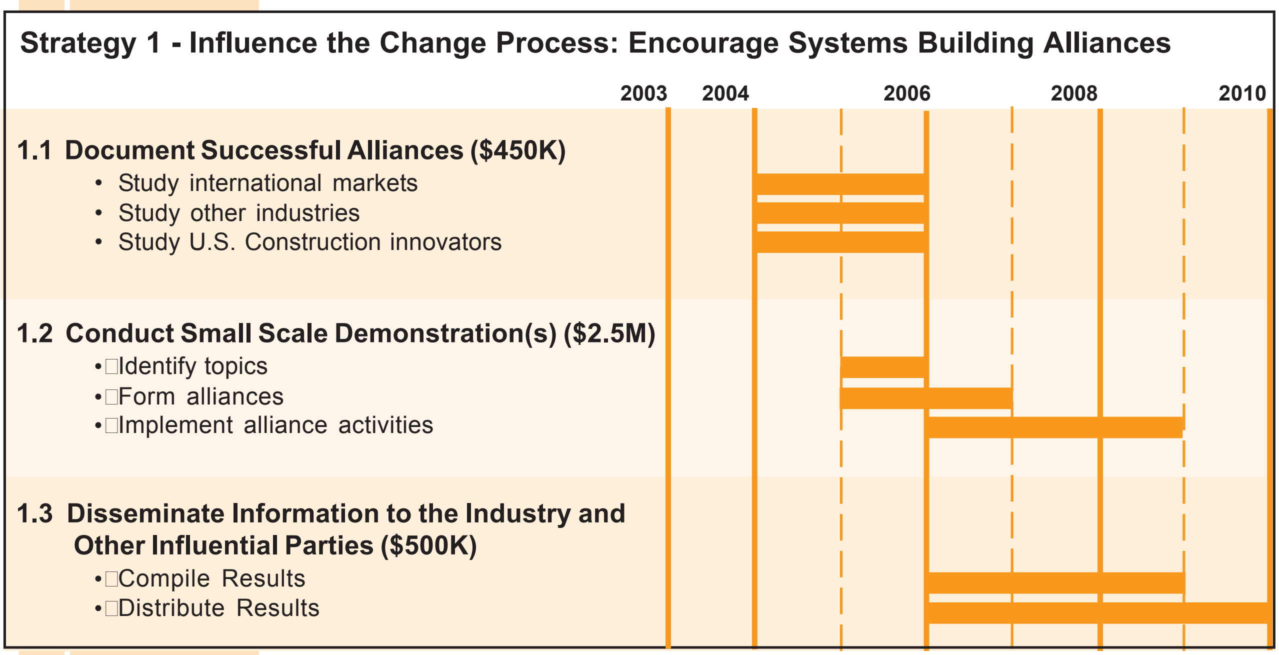

Figure 1

1.1 Document Successful Alliances

The roadmap participants through the entire process stressed the need to take advantage of the work done to date as much as possible. A series of actions were suggested to describe efforts that may represent a model to follow.

Initially, PATH should study the housing structure in other countries to document successful alliances. Europe, Japan, and Australia all were cited as locations where consortia have been operating successfully. Likewise, other industries in the United States and elsewhere are working cooperatively to address issues that cut across their industries. These include industries that are dominated by a few large companies such as the auto industry, as well as industries that are as fragmented as the building industry. For example, the Software Productivity Consortium represents a broad group of participants with a mission to serve its members "by providing highly-leveraged system and software technology and services to increase productivity, profitability, and competitiveness."

A third area that should be studied is the actual construction industry. There are examples of successful systems approaches, although not widely adopted, that need to be studied and disseminated to the rest of the industry. The best examples from those that have taken a systems approach to at least part of the design and construction process should be valuable to the entire industry. Examples might include large commercial contractors who are involved in both housing and other construction, international construction firms involved in construction management and military family housing, and producers of manufactured housing.

1.2 Conduct Small Scale Demonstration(s)

A demonstration that shows how change can be managed to facilitate a systems approach is the heart of this strategy. The groups cited an initial need to identify appropriate demonstration topics. Clearly, PATH or a related alliance could not simply attempt to change the entire process through a single demonstration. Starting with “small steps” is more likely to show others how to approach their specific issues. An example of a topic might include effectively designing a home by integrating multiple subsystems into one cooperative effort. For instance, the electrical and communications systems could be designed as part of a wall panel system to encompass design and layout of the home as well as the physical placement of the wiring. Or, a larger effort at a whole system level may be appropriate.

The formation of an alliance of stakeholders willing to tackle one of the topics would be the next logical activity. The alliance should include participants potentially up and down the supply chain such as: builders, trade contractors, code officials, designers, and researchers. In order to accomplish the goal of change in the process, it is important in this demonstration that the players be innovative. For example, we may want to involve builders from the commercial sector, or very large home builders. As the project matures, other stake holders will need to be brought into the alliance.

The alliance members should set goals of the project, identify activities and roles of each stakeholder, and set up a process to coordinate the activities. The alliance will then implement and document their activities through successful construction of a group of homes.

1.3 Disseminate Information to the Industry and Other Influential Parties

Under this set of activities, the information documented in 1.1 and 1.2 will be compiled for distribution to the industry. Dissemination activities should include a wide variety of approaches including development of information for high-profile web sites such as Builder Online or HousingZone.com, releases to the media, trade show presentations, and distribution through State and Federal agencies, builder associations, manufacturing associations, and building official organizations.

2 INDUSTRIALIZE THE HOMEBUILDING PROCESS

There are three main activities under this strategy: application of manufacturing processes and technologies to homebuilding that have proven successful in other industries; barrier removal; and study the potential for robotic applications.

Strategy 2 - Industrialize the Homebuilding Process

2003 2004 2006 2008 2010

2.1 Apply Manufacturing Processes to Homebuilding ($1.5-$2M)

- Identify processes used in manufacturing environments and assess applicability
- Identify manufacturing processes or technologies being used in the homebuilding industry
- Solicit new ideas through design competitions
- Demonstrate processes and provide technical assistance

2.2 Remove Barriers to Industrialization of the Site-Built Environment ($4-$6M)

- Identify opportunities for efficiency improvements
- Identify barriers to efficiency improvements
- Conduct research and dissemination activities to remove barriers and demonstrate efficiencies

2.3 Examine Robotic Applications ($100-$150K)

- Review robotic applications in construction nationally and internationally with recommendations on those with greatest potential for residential construction

Figure 2

2.1 Apply Manufacturing Processes to Homebuilding

Very few builders have adopted management processes used in the manufacturing sector, although many of these have application to the construction site. Those who are implementing these processes are for the most part larger volume builders. Today's information technologies are now opening up opportunities for expanded use of some of these practices that were once out of the question for small and medium-sized builders. Roadmap participants specifically cited the opportunity to move the younger generation of builders into these practices, believing that they are more inclined to adopt computer-based management systems. Several activities need to occur in order to move this part of the strategy forward:

Identify and assess processes used in manufacturing environments that may be applicable to homebuilding - This activity will require information gathering to compile, analyze, and characterize approaches that have been used successfully in other industries. An example would include concurrent engineering and design, where communications between the designer, builder, purchaser, foreman, trade contractors, and others involved in the design and construction of homes could improve the efficiency of the entire process and result in a better product, higher margins, and higher customer satisfaction. All phases of construction would be considered simultaneously with an aim to create housing with few call backs, shorter production time, and lower cost.

The processes used in manufacturing are certainly more easily integrated within today's information technology infrastructure. However, many of the techniques used in other industries are not necessarily computer-based. Examples include just-in time (JIT) manufacturing, which reduces the need for maintaining large inventories, and even-flow production, a process that offers more predictability in the scheduling of activities.

Once processes are identified, they should be assessed to determine applicability within different parts of the industry, e.g. different size builders or market niches. The study should identify the potential for integrating specific manufacturing processes into particular trades or activities at different points in the homebuilding process.

Identify and assess manufacturing processes or technologies being used in the homebuilding industry that can be adopted on a broader basis - Some builders have begun to use manufacturing techniques in site-built settings, including continuous improvement methods and even-flow production. However, manufacturing techniques have more often been applied by manufactured, modular, and panel home producers. Each of these sectors of the industry should be investigated to identify successful applications of manufacturing techniques that could be more broadly implemented by the site builder.

Solicit new ideas through design competitions for students, designers, and manufacturers - Design competitions have always been a relative low risk way of generating new ideas. Unlike other building industry programs of this type, PATH should work to develop programs that reach out to the manufacturing community. This would include competitions aimed at manufacturers themselves, but also students and professors at schools with a manufacturing emphasis.

Demonstrate and evaluate processes from findings and provide technical assistance to small and medium-size builders in implementing these processes - Once the most promising manufacturing technologies have been identified, PATH should take a lead role in working with industry to demonstrate them and document their adoption by selected builders of various sizes and types (small volume, large volume, custom, speculative, etc.). Documenting of the adoption process should be emphasized and the results turned into guidance materials specifically for each type of builder. A program should be put in place that would allow for on-going assistance for smaller builders during the implementation stages and to collect feedback on different processes over time.

2.2 Remove Barriers to Industrialization of the Site-Built Environment

The introduction of industrialization into a site-built environment offers many benefits, but it also offers its own set of barriers that first must be removed or addressed. For example, cycle-time on a site has a lower limit that is restrained by forces having little to do with the physical construction of the home. Work stoppages for inspections, delays in waiting for other elements in the critical path to be finished, supply delays, and specialty trades are some examples of these forces. Without these constraining forces, it would be possible to build a home from start to finish in as little as two weeks. Specific activities to address these issues are as follows:

Identify opportunities for efficiency improvements - The first activity under this project is to lay out the way a home should be built without being restricted to how it is currently built. For example, is it necessary to have different crews for the slab preparation, ground works, and concrete flatworks? One builder in Cleveland has successfully trained crews to do all of these tasks in place of individual trade contractors. He, in effect, builds the home around a logical set of activities rather than according to trade activities. By studying how others have addressed innovation in this area, PATH can begin to compile a list of potential opportunities for further evaluation and implementation.

Identify barriers to efficiency improvements - Once opportunities are identified for efficiency improvements, the barriers to these opportunities need to be identified. In many cases, the barriers will be evident, but additional research through interviews with key members of industry should be conducted. Some of the barriers will be market-oriented while others will be regulatory in nature. Market barriers might include a lack of skilled labor or warranty requirements. Regulatory issues would likely include licensing requirements for each trade or inspections.

Space constraints are often the driving force behind the lengthy cycle times in construction. One trade must wait until another trade is complete and then they must clear out rapidly themselves to give the next trade room. Is it possible to conduct activities that have traditionally been done in consecutive order at the same time? Some builders have addressed the space issue by building off-line assembly buildings that are turned into community centers or individual homes when the construction is complete. These and other opportunities to remove barriers need to be identified and disseminated to the industry.

Conduct research, dissemination, and other implementation activities to remove barriers - The last step is actually a set of activities geared toward removal of the barriers for each opportunity. Tasks could include developing model legislation to remove regulatory barriers, development and training of laborers or trade contractors, and demonstrations of successful techniques.

2.3 Examine Robotic Applications

The PATH Whole House Roadmapping team identified the application of "robotic automation and information technology" as an area of interest because it presents opportunities to increase industrialization of the homebuilding process. A series of potential PATH-supported research activities in this area were laid out in the Year

One Progress Report. Since that time, additional background information has been gathered and opinions have been solicited from various participants and observers. Based on this work, the present report lays out a modified approach to further PATH work involving automation and robotics, as discussed below.

Although, there is no single accepted definition, for present purposes, a "robot" can be considered a type of automated machine; that is, a machine that operates under computer control and incorporates some element of feedback or adaptive response that serves as a primitive form of "intelligence." A "robot" should also have some degree of general mobility, whether of a robot "arm" or of the entire device. Note that some devices referred to as robots are designed to be operated by a human being using remote control. There is a gray area between robots and automated machines. One important difference is that automated machines require less mobility than robots and therefore are less challenging to make and program. Automated machines are well suited to assembly-line type operations where a product is automatically brought to the machine during manufacture, and are widely used in this way by industry. There are analogies between the general manufacturing environment and the production of manufactured housing or modular homes, and even closer parallels to the production of roof trusses, wall panels, HVAC equipment, windows and many other items used in building houses. Thus, it is reasonable to expect automated machines to be introduced and used in factory settings before being adapted for other environments. That process is beyond the scope of this roadmap, which focuses on potential robotic applications in the site-built sector.

Site-built construction, whether residential or commercial, is a very different story than factory production. In the site-building environment an automated machine will most likely need to be more robot-like to be useful, since it must move to and around the work being performed in an environment that is loosely structured at best. Environmental conditions at the building site are far more variable than inside a factory, making reliable operation more difficult to achieve. Rather than autonomous robots, it may be more realistic to expect this type of technology to be introduced to site-built construction in the form of machines that perform repetitive, difficult, or dangerous tasks under some degree of local or remote control by a human operator.

Despite the obvious challenges of achieving mobility together with functionality, simple robots have actually begun the transition from science fiction to mainstream consumer technology applications. Examples include:

- robotic lawnmowers (the "Robomower")
- robotic vacuum cleaners (the "Roomba")
- robotic pool cleaners (available from several manufacturers)

These applications are low-skill, repetitive operations.

Each of these robots performs a useful labor-saving function automatically and inexpensively. Yet the consumer environment scarcely hints at the market potential. There is a strong interest in developing useful applications of robots for all types of industry, including but not limited to construction. This is testimony to their potential to save time, to reduce costs by substituting capital equipment for labor, to improve accuracy and quality of the finished job, and to remove workers from hazardous environments.

It is very important to recognize the depth of interest in robotic technology in general, and construction applications in particular. There are national and international trade associations devoted to robotics, including the International Association for Automation and Robotics in Construction (which publishes the Catalog of Robots and Automated Machines in Construction), the International Robotics Council, the U.S. Robotics Industries Association, and Robotics and Automation Society which publishes *Robotics & Automation* magazine. IMS is an international organization dedicated to advancing "Intelligent Manufacturing Systems" through consortia-sponsored R&D activities. One program organized through IMS is "FutureHome", a multi-year European effort to reduce housing cost and improve quality through the use of advanced manufacturing technology.

In terms of the underlying research, there have been a total of nineteen *International Symposia on Automation and Robotics in Construction*, with the most recent one held at the National Institute of Standards and Technology (NIST) in 2002. The international academic research journal Automation in Construction has been published since 1992. There are several university research centers devoted to robotics, including the Construction Automation and Robotics Laboratory at North Carolina State University and the Robotics Institute at Carnegie Mellon University. There are also many other university engineering departments in the U.S. and around the world that have published materials on the subject.

Some participants in PATH roadmapping have commented that robotic technology is too far removed from the present to be relevant to PATH. It is true that despite sustained interest, many years have been required to bring the technology even to its present state of development. It is also true that there are still few if any near-term opportunities to even demonstrate robotic technology in low-rise residential construction. Yet given that the field has been and remains the subject of a large amount of research around the world it would be shortsighted to dismiss robotics completely from PATH, whose purpose is to accelerate the adoption of beneficial new technologies.

There are a variety of applications that have already been demonstrated, some extending back more than a decade. Japanese companies, in particular, have pioneered the use of robots in construction for tasks including concrete distribution, leveling, surface treatment and finishing, spray painting, and spray-applied fireproofing. Other applications include robots for welding steel building frames, remote-controlled demolition equipment, and remote-controlled earth-moving equipment. The dominance of Japanese firms in this area may reflect the size and economic power of the large conglomerates in that country's heavy construction industry.

Examples of Demolition Robots

Courtesy Photos: Brokk Inc.

At a more developmental stage is a fully robotic computerized intelligent excavator developed at Lancaster University in the U.K. This device can ultimately be enhanced to do trenching, to use GPS technology for navigation, and even to perform the cut-and-fill process required for economical grading of large sites or subdivisions. Prototype robots are under development for bricklaying, and for assisting in hanging drywall. Entire projects have been organized around the underlying concepts, including the "Intelligent Field Factory", designed to develop techniques "for the automated assembly of large structures such as factory facilities."

Experience indicates that it will take many years and large investments before robots find their way into routine use in homebuilding. In this field, as in several others, applications are likely to be derived from successful uses pioneered in housing factories, or perhaps in civil engineering or heavy construction, where larger firms can absorb the expense of development. PATH should prepare itself by gaining a better understanding of current applications and keeping abreast of developments. Robotics should be reviewed again in future Whole House Roadmap editions.

3 IMPROVE THE CONSTRUCTABILITY OF HOMES

There are many potential ways to improve the constructability of homes which could increase their efficiency, cost effectiveness and performance. The roadmap work group focused on three main strategies as a starting point for this effort, and to provide for some focused activities. This is not intended to be an all-inclusive list of strategies and/or activities. What follows is a discussion of three strategies that were frequently acknowledged as important and appropriate for PATH.

Source: PATH Field Evaluation

Typical utility installation demonstrating lack of integration.

The first two strategies are related to the mechanical systems and utilities, including HVAC, electrical, communications, security, and plumbing. Many of the comments offered on the strategies identified these activities as the most important to the builder and trade contractor because these systems have such a large impact on other systems, schedules, and overall cycle time. The activities or projects are not prioritized and would need to be performed either sequentially or as parallel activities.

The third strategy deals with designing homes so they are less complicated to construct. In many ways, this will result as homes are built using manufacturing efficiencies. Examples include reducing the number of parts through panelization and using technologies that serve multiple functions such as structure and finish. Delivering these capabilities or features will require extensive development of design tools. Another example is to build prototypes using the open building techniques that separate the base building along with mechanical systems and utilities from the rest of the unit. Some of these ideas overlap with Strategy 4 - Creating Better Living Environments.

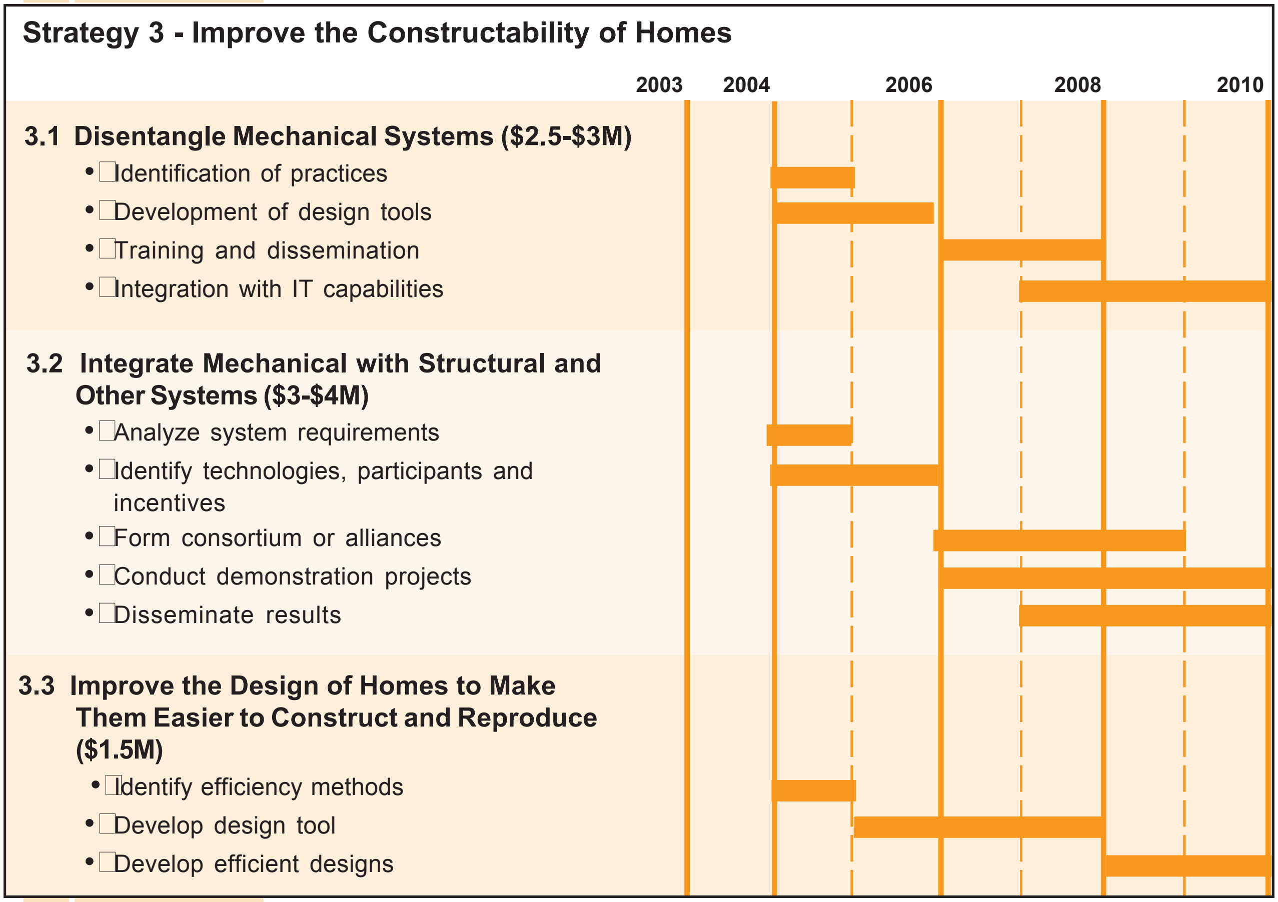

Figure 3

3.1 Disentangle Mechanical Systems

The primary objective of this strategy is to improve the design and installation of existing mechanical systems and reduce interference among the various systems. In many ways, this amounts to developing tools that can help designers and installers of the various systems communicate with each other and to optimize the installation of each system. Activities include:

Identification of practices that minimize interference among systems - A search and review of alternatives is the first activity. Examples of methods that could reduce interference include surface-mounted communications systems using ultra-thin wiring or fabric-based wiring systems; design techniques that minimize duct runs or eliminate plumbing vents; or even technologies that eliminate or minimize utilities such as mini-split heat pumps that require no duct work, wireless thermostats, or wireless electrical switches. These techniques should be compiled and made available to builders, trade contractors and designers.

Development of design tools - One of the most significant issues identified by roadmap participants is related to the interference and lack of coordination between different trades. Under this activity, PATH could initiate the development of tools for design of various systems that consider the room functions, other utility systems, and the structural systems. Primary emphasis should be on the routing of utilities and production of clear installation details.

The design tool should begin with a set of guidelines for each system designer and installer to consider. A more advanced design tool should then be developed in the longer term. This should start with the interaction of several of the key subsystems (e.g., HVAC and structural) and then would be expanded to a comprehensive tool that integrated the design of the major systems to minimize or eliminate overlap. Results would create a situation where the heating/cooling registers would be located to minimize duct runs, the plumbing layout would eliminate interferences with the ducts, and each subsystem would be designed to eliminate the need to modify structural components on site.

Wireless Thermostat

Courtesy: ENERNET Corporation

Training and dissemination - Getting the word out on the design techniques and tools is critical to the success of this strategy. As with any new tool, an effort must be made to train users, including designers and installers, on its implementation. A technical assistance program should also be put into place to provide on-going assistance.

Integration with IT capabilities - Training of designers and installers on the use of tools and guidelines is a good start. A longer-term step would be to deliver the information, including installation details, to the job site and to allow for changes to be processed immediately. The IT world has many different possible solutions for delivering information to the site. These should be explored and tools developed in cooperation with the IT industry.

3.2 Integrate Mechanical Systems with Structural and Other Systems

At the same time as we are improving the efficiency of existing mechanical systems, the opportunity exists to better integrate different functions or subsystems in the home to further improve efficiency. The first necessary activity is to conduct an analysis of the system requirements. In other words, we need to identify the basic performance and functional requirements of each subsystem to look for opportunities to integrate them. The roadmap group specifically identified the mechanical and structural subsystems as opportunities for merging functions and thus reducing material and labor costs and improving cycle time.

The second activity under this strategy would be to identify potential technologies, participants, and incentives. For example, incentives are particularly important if we want manufacturers to participate. It will be incumbent upon PATH or others to work with manufacturers who have a natural inclination for innovation to show them how they can benefit from integration of different subsystems. One approach is to sponsor a competition to assist manufacturers with funding R&D efforts to integrate various functions with current products. The Small Business Innovation Research (SBIR) model used by many of the Federal agencies may be appropriate to encourage manufacturer participation.

Once the participants are identified, a consortium or alliance should be formed to develop systems solutions. The alliance could be an extensive group of manufacturers from a broad cross-section of disciplines working to integrate multiple functions into a single technology or product. At the same time, smaller alliances targeting incremental improvements should also be pursued. These may be as simple as one or two manufacturers working together with PATH to address specific opportunities to increase efficiency of the design and construction process. The alliance or manufacturers should be charged with developing goals, defining activities and roles, and moving the activities forward. The alliance activities should be documented and assessed as part of a demonstration project. PATH should take an active role in disseminating results.

3.3 Improve the Design of Homes to Make Them Easier to Construct and Reproduce

The objective of this strategy is to approach the construction of a home more like a manufacturer would approach the design of a product. This would include looking at efficiencies such as reducing the number of steps in a process or the number of parts assembled in the field. It would also include architectural design improvements that make the home more functional. For example, using flexible, open space can allow for multi-functional space or can give the feel of a larger space than the same area in a traditional room layout.

The first activity is to identify methods for reducing material and labor requirements. This would include analysis of known practices such as advanced framing techniques and broad searches of the industry to uncover additional techniques. Many of these techniques are expected to be immediately applicable to volume builders. Thus, an output from this task should include a set of home designs or design techniques that use the most-promising techniques.

To make progress at increasing the efficiency of home designs, the roadmap also needs to address the smaller builder and the custom home market. The roadmap group identified the next step as development of a design tool to optimize house design. The tool would need to address multiple parameters such as cost, energy efficiency, material selection, and other issues that are part of developing an optimum design. The tool would enable designers to evaluate different scenarios with each subsystem and to converge on the most efficient overall design based on a set of objectives defined by the user. The final activity would be to develop designs for small builders using the design tool.

4 CREATE BETTER LIVING ENVIRONMENTS

Homes that provide a safer, healthier environment and that fulfill the functional requirements of the occupants in an optimal manner are well within our reach. However, the way in which we approach the design and construction of homes often inadvertently limits the ability to consider issues that affect the liveability of homes. Typically, the design is approached in a fragmented manner, whereby the floor plans and architectural features are developed by one individual and then given to the various subsystem designers to "make it work." Even at the subsystem level the little interaction that occurs is often adversarial, not cooperative. The goal of this strategy is to incorporate systems thinking into the overall home design so that the end result is an affordable, flexible, high quality living environment for the occupants.

This strategy runs the risk of being overly broad, since it can include a large number of issues. However, the focus at this point is on several high priority items that have been identified by the Roadmap participants. These include systems-based approaches to improve the living environment and functional performance of homes, as well as the removal of barriers that restrict the adoption of innovative technology.

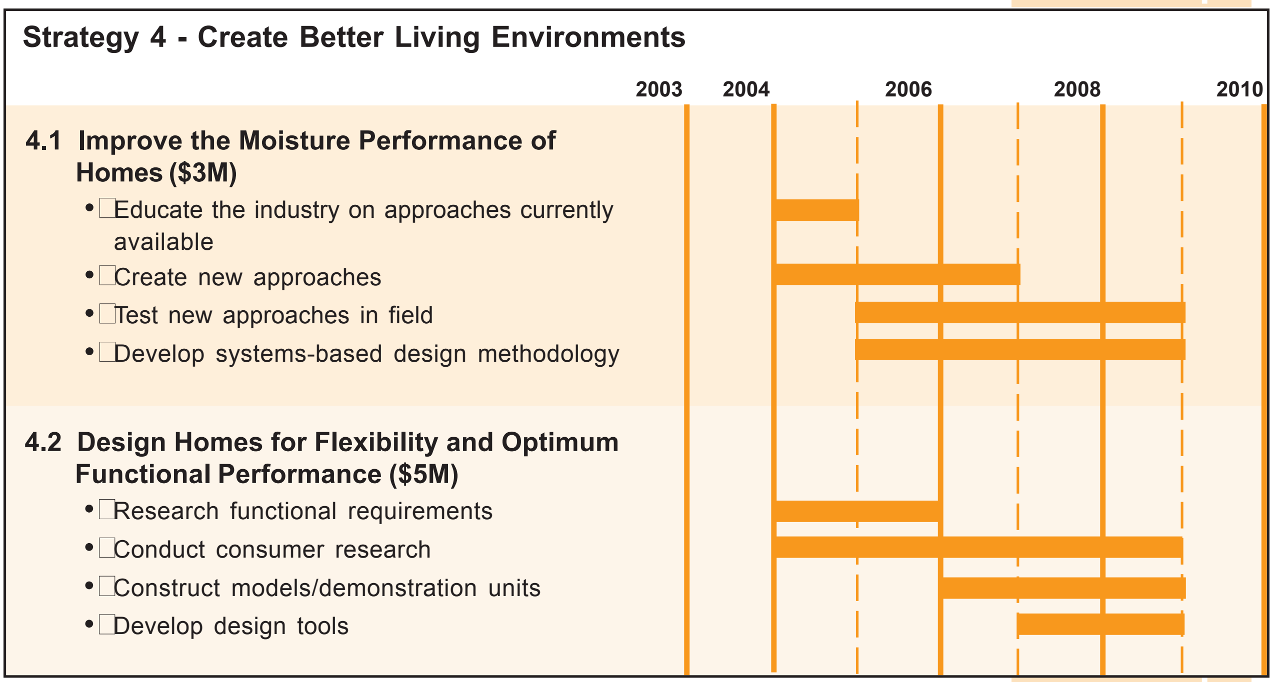

Figure 4

4.1 Improve the Moisture Performance of Homes

Moisture is a topic of discussion at nearly any building industry event these days, and for good reason. The evolving litigation and insurance crisis rooted in moisture problems threatens the affordability of homes and poses a significant barrier to the adoption of new materials and processes. The goals of this strategy are to develop approaches for improving the performance of the home relative to moisture to:

1. Provide a healthy indoor environment
2. Protect building materials from pre-mature failure, and
3. Remove a significant barrier to the adoption of innovative technologies.

Many subsystems in a home are impacted by moisture or themselves can contribute to moisture problems. Moisture levels are influenced by the occupant activities in the home. Likewise, the HVAC system and the tightness of a home influence moisture levels. These resulting levels, in turn, affect the durability of structural and finish systems. Yet, most subsystems are designed individually with little regard for their impact on the home as a whole. A systems approach is needed where the full impact of changes in one part of the home, such as the introduction of a new structural material, are understood and considered in the design and construction of homes.

Specific activities to achieve this strategy are discussed as follows:

Educate the industry. Immediate steps are necessary to impact the homes that are now being built. Mainly, this must be accomplished through education of builders and trade contractors. This task should not require significant new research to develop educational materials. Rather, it should focus on compiling existing information and disseminating it to designers, builders, trade contractors, code officials, and others.

Courtesy: Steven Winter Associates, Inc.

Mold on basement wall

Create new approaches to better address moisture issues - There are many ways to change the way homes are built that can help alleviate moisture problems. Some of these are straightforward and can be implemented in the short term while others will require longer-term efforts.

- One approach is to demonstrate the feasibility of adding "moisture specialist" to an existing trade. PATH would need to investigate how to increase the value added by combining the functions of multiple existing trades into one trade, rather than creating an entirely new trade. A moisture or envelope specialist may take responsibility for all of the trades that impact moisture through the building envelope. For example, insulation trade contractors may expand to address windows, doors, flashing, and final grading as part of their services. Some of this combining of trades is already occurring and PATH could help to accelerate its acceptance.

- Other approaches to consider might be a professional status for moisture specialists. This could include a certification program for designers or installers in the short term and curriculum development for schools of architecture, construction, or housing in the longer term.

- Another possible approach is to create "code and insurance industry-approved" methods for moisture using conventional materials. These methods could be tied to legislation that removes liability from designers and contractors who comply with them.

Test new approaches in the field - Once new approaches are identified, PATH should conduct a series of field tests to document them. This could lead to larger-scale demonstrations of the most successful approaches.

Develop a systems-based design methodology to moisture for existing and innovative technologies. This would require a series of tasks to:

- ✓ Identify performance requirements for main subsystems related to moisture. These will be especially useful for designs using innovative materials.
- ✓ Encourage regulatory approval of designs that can meet the performance requirements.
- ✓ Develop design tools for the subsystems and systems that relate to moisture.

4.2 Design Homes for Flexibility and Optimum Functional Performance

Making homes more livable will require the integration of multiple subsystems into a whole-house approach. The goal of this strategy is to provide the industry with tools to integrate the desires of occupants, including functional requirements, with the design of various subsystems in the home. An emphasis is placed on merging design issues like room layout and function with technological innovation.

An initial approach is to identify functions, design features, and technologies that can increase the flexibility of homes. For example, the ability to change the function of a space over time as a family grows and contracts or as functional requirements change as people age will make the home more liveable. Methods for identifying these approaches include typical activities like review of existing literature and interviews with leading edge designers. Other ways to identify opportunities would include design competitions, a workshop or conference, and technology scanning. The results of these initial activities should be disseminated to the industry on an on-going basis.

Another necessary task is to conduct consumer research to identify the various functions homebuyers expect or desire in homes at various levels (entry, move-up, luxury). If homes are to become more flexible and allow people to live in them despite changes in their requirements over time, we also need to understand functional needs and desires during different seasons in life.

Constructing one or more models of flexible houses or components is valuable.

Building on efforts such as the research work sponsored by PATH (An Integrated Interior Infill System for Mass Customized Housing) currently underway at the Massachusetts Institute of Technology together with the University of Central Florida, units or subsystems might be constructed and tested.

A final activity is to develop design tools for builders that allow a systems-based approach to increase flexibility and functional performance. In the short term, guidance documents may be satisfactory for use by designers. However, the complexity of some solutions will likely require the long-term investment in software development.

Future Roadmap Activities

This roadmap outlines strategies and activities that need to take place through 2010. It is important to keep in mind that it is not an exhaustive list. The working group suggests that this roadmap be revisited in about two years, along with the findings of projects completed to date. The progress will allow the groups to add additional activities and expand strategies as appropriate.

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