Research and Development Needs for Structural Performance of Light-frame Residential Construction

Workshop Report
Tuesday, July 24, 2001

Prepared for
Partnership for Advancing Technology in Housing

Prepared by

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

Washington, DC

January 2002

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Partnership for Advancing Technology in Housing (PATH) is a new private-public effort to develop, demonstrate, and gain widespread acceptance for the "Next Generation" of American housing. The goal of PATH is to improve the quality, durability, environmental efficiency, and affordability of tomorrow's houses through the use of new and innovative technologies.

Initiated jointly by the Administration and Congress, **PATH** is managed and supported by the U.S. Department of Housing and Urban Development. In addition, all Federal Agencies that engage in housing research and technology development are PATH partners, including the Department of energy, the Department of Commerce, the Environmental Protection Agency, and the Federal Emergency Management Agency. State and local governments and other participants in the public sector also are partners in PATH. Product manufacturers, homebuilders, insurance companies, and lenders represent private industry in the PATH partnership.

To learn more, please contact: PATH, email: pathnet@pathnet.org

SECTION 1. BACKGROUND

The Partnership for Advancing Technology in Housing (PATH) advances Technology in the home building industry 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, and labor safety.

The PATH mission is to improve housing affordability and value by advancing housing technology. As such, three overarching goals have been established that bear on our houses' costs, energy-efficiency, environmental impact, quality, durability & maintenance, hazard mitigation, and labor safety. The goals are:

I. To determine the needs for improved housing technology development and to provide relevant strategic services.

PATH will investigate the institutional barriers that impede innovation, will propose alternative, improved, or negotiated services to overcome those barriers, and will develop networks and agreement among participants to implement these services.

II. To develop new housing technologies.

PATH will support and perform technological research at all R&D levels of the home building supply chain link with governmental and industrial funds and resources.

III. To disseminate new and existing technological information.

PATH will coordinate dissemination of innovation information (both for specific technologies and for industry-wide technological information) that remains unbiased, technically accurate, and relevant to specific housing audiences to increase the familiarity with, availability, and use of technologies in the home building and home owner communities.

Partners in the PATH program—the U.S. Departments of Housing and Urban Development, Energy, and Agriculture, the Environmental Protection Agency, and the Federal Emergency Management Agency, as well as 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, the PATH program partners recognize the importance of setting priorities for research and technology development that will enable the home building industry to work towards the PATH mission. This priority setting is known as "roadmapping," which will be presented in Section 3 of this report.

The PATH Roadmapping Process was initiated at a meeting in Kansas City in March, 2000, when a group of builders, materials and product suppliers, academicians, and other stakeholders broadly assessed technology areas that might permit significant progress in helping PATH address the key housing attributes of affordability, energy efficient, environmental concerns, durability, and safety. The meeting identified three technology areas that show great promise: information technology, panelized-type systems, and whole-house and process redesign. Subsequently, roadmapping groups assembled to address each of the three areas. Reports are being prepared for each of them.

SECTION 2. VISION & ROADMAP SUMMARY

Though falling outside of the three established roadmapping endeavors, this effort to establish research priorities for structural performance of light-frame residential construction can be considered a part of the overall PATH Roadmapping effort. It provides a view of how future R&D efforts in this area (both public and private sector efforts) can support the goals of the PATH program in relation to structural performance of light-frame residential construction—an area and discipline that PATH believes requires a distinct roadmapping effort.

In July 2001, representatives from universities, trade associations, product manufacturers, and the government met to identify critical R&D needs for structural structural performance of light-frame residential construction. As a result of this one-day workshop, five research topics were identified as critical. They are:

- Data Warehouse - Establish a data warehouse or a repository that would house all data from past construction research, including but not limited to; tests and testing, loads and loading conditions, structural performance, durability, energy efficiency, ease of construction, construction costing, and construction quality.
- Performance Requirements - Develop performance requirements including quantification and standardization of performance expectations as well as performance requirements for the introduction of new materials in construction projects.
- Defect Study – Study the concept of what is truly and scientifically a "defect." Define what a defect means within a construction project. Collection of defect data to quantify defects and their statistical significance. Determine the cause/effect relationship between defects and construction performance.
- Contribution of Nonstructural Components to Building Performance - Develop methods, including general analytical models, to study the contribution of nonstructural components to the overall structural performance of construction.
- Technology Transfer to End-Users: – Develop and/or expand on existing tools and work with current industry groups with on-going knowledge/expertise to implement technology transfer of any new technology created to end-users of this technology.

Please note that the subject matter addressed in this report is very focused. Accomplishment of the recommended activities in this report will help facilitate some of the goals in each of the three major roadmapping areas mentioned above.

The participants recognized that though the amount of Federal R&D funding in general and fundamental research areas has been modest, Federal funding nevertheless represents the largest single contribution. Though the role of the Federal government in this R&D effort was not specifically addressed due to lack of time, the workshop participants' views were clear on how R&D efforts should be carried out. They would like the Federal government to avoid supporting R&D that would result in the development of proprietary and/or private new materials and structural systems. The participants felt strongly that the Federal government should support setting targets for new product development, setting up test protocols, and providing support for the development of modeling capability. They also expressed the need for collaboration on these R&D activities.

The specific vision for this roadmap is to **"build better homes through a focused R&D strategy in structural performance."** Several tasks critical to meeting the vision were examined in this report:

- Identification of the critical research and development needs and current information gaps that we have so that we can better understand structural performance.

- Recommendation of how needs can be satisfied and information gaps filled.

- Description of the role of the federal government, particularly HUD, in implementing whatever strategy is developed

SECTION 3. ROADMAPPING PROCESS

The objective of PATH technology roadmapping is to identify research areas in home building to guide government and industry investments in research. The PATH Industry Steering Committee (ISC), comprised of builders and manufacturers of building products and materials, oversees the development of all technology roadmaps.

As the primary planning activity for PATH's research, 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. Roadmaps approved by the PATH ISC will be provided to private sector interests to guide their technology development and to the government to guide its investment in research and development. So, new technologies as well as additional research work are generated as the roadmaps get implemented.

The PATH ISC initiated the roadmapping process in Kansas City in March 2000. A group of 40 builders, suppliers, and researchers identified and rank-ordered technologies that hold promise of contributing to achieving one or more PATH goals. The ISC then assembled the technologies with the highest potential benefits into three technology portfolios as follows:

- Information Technologies to Accelerate and Streamline Home Building;
- Advanced Panelized-type Systems; and
- Whole House and Building process Redesign.

PATH decided to develop technology roadmaps for each of the three areas, starting with the Information Technology in November 2000, Advanced Panelized in December 2000, and Whole-House in March 2001. Roadmapping reports for all the three areas are being prepared. Current versions are available at www.toolbase.org (click on “Research” on the top navigation bar) and www.pathnet.org.

As a complement to these roadmaps, the Structural Performance roadmap will provide additional resources to researchers and industry leaders in setting out new areas of exploration for materials and structural knowledge pertinent to housing.

SECTION 4. SITUATION TODAY

Current R&D activities on the structural performance of light-frame residential construction can be described as inadequately funded and fragmented, with a large number of uncoordinated sponsors and minimal collaboration. As a result, many researchers are working in isolation. Synergy in housing research happens by chance, not through a concerted effort in participation. There is no strategic plan, nor has the leadership been identified that is necessary to lead and implement such a plan.

PATH's mandate is to facilitate and, therefore, to maximize the impact of Federally funded research. In March 2001, HUD PD&R's Division of Affordable Housing Research and Technology distributed a white paper that summarized the results from a worldwide survey of researchers at universities, private and public organizations about their light-frame residential construction R&D activities. The paper, entitled *Research and Development Activities on Structural Performance of Light-frame Residential Construction* proposed a workshop involving key individuals from the structural research arena to develop directions for future R&D, develop a list of action items that would lead to the execution of the projects identified, and address the Federal and industrial roles in such research.

SECTION 5. ROADMAP

5.1 The July 24, 2001 Workshop

The workshop was held at the Falls Church, Virginia campus of the Virginia Polytechnic Institute and State University on Tuesday, July 24, 2001. Its agenda is provided in Appendix B. The plenary session provided an opportunity to establish the goals and tasks of the workshop. The white paper described in Section 4 provided background for the day's discussions. The workshop participants were assigned to two concurrent sessions, A and B. The session assignments were intended to balance the background of the individuals and provide a broad range of discussion. Following several hours of discussion, the group findings were presented in a plenary session. The workshop concluded with discussion of the three (five?) tasks described in Section 2.

The 34 participants represented a broad perspective of the housing industry (See Appendix C). The level of interest in participating in this workshop was impressive, demonstrating a strong commitment to finding ways to improve future performance of housing stock. The concurrent session format reduced the number of people in each session therefore elevating the level of each member's participation.

5.2 Recommended Lists of R&D topics from the Workshop Participants

Each session identified a prioritized list of topics during the general discussion (see Section 7 below). Each session identified research topics and presented priorities for the topics. Session A developed and ranked 12 topics and Session B identified 17 topics. They are:

Table 5.1
Session A - Recommended Topics

Topic	Rank
Data warehouse (load, performance, construction, and quality)	1
Effect of defects on performance data (include defect data and defining "defect")	1
Quantify performance expectations in aging (define quantification)	3
All less than 30 feet structural wind load data	4
New materials/systems and technologies research (to be less on-site problem prone)	5
Modeling, simulation, testing of performance of construction systems (from members to systems)	6
Contractor education/outreach/certification	6
Seismic load and design related to light-frame performance	8
Materials (durability, aging)	8
Retrofit vulnerability, measures, tools	8
Roofing performance prediction	11
Flood data (erosion effects, material resistance, wave measurements, and debris flows)	11

Table 5.2
Session B Recommended Topics

Topic	Rank
Performance requirements (allow new materials)	1
Nonstructural components and general analytical model	2
Technology transfer to builders	3
Durability assessment and performance modeling of housing systems	4
Technology for retrofitting existing homes	5
Dynamic wind load discussion, field data	5
Short-term testing for long-term performance (accelerated testing)	5

Ground speed wind	5
Degradation model and measurement with moisture and durability – no bugs	9
Protocols for transferring knowledge from lab to full to field	9
Synthesis of green and life-cycle costing	11
Systems approach design	12
Safety considerations	13
Aerodynamic alleviation, deflectors, etc.	13
Develop metrics for building component performance comparison	13
Degradation model	16
Economic life-cycle	16

5.3 Prioritized R&D List

No attempt has been made to integrate the two lists of priorities. Instead, the top three topics from each list will be discussed.

From Session A (Table 5.1):

- Data warehouse (load, performance, construction, and quality).
- Quantify performance expectations.
- Effect of defects on performance data, including defect data and defining "defect."

From Session B (Table 5.2):

- Performance requirements (allow new materials)
- Nonstructural components and general analytical model.
- Technology transfer to builders.

The six topics were regrouped into five as shown below:

a. <u>Data Warehouse</u> - Establish a data warehouse or a repository that would house all data from past construction research, including but not limited to; tests and testing, loads and loading conditions, structural performance, durability, energy efficiency, ease of construction, construction costing, and construction quality.

A good database is fundamental for any successful R&D effort. Data that have been and will be collected take many forms including those from all types and scales of testing, modeling, long- and short-term field evaluation and demonstration, and housing performance under extreme conditions such as those imposed by natural disasters. This data, at a minimum, should include the history of houses with respect to their load, load path, quality control during construction, and performance through their service life as well as under extreme conditions. Such data exists in many different forms and is maintained at many different locations. The scattering and unevenness of existing data sets limits their use. Their different locations make access difficult, and in cases when it is private or proprietary, impossible. Certain types of proprietary data are not available unless the data's owner concurs in its use. In spite of these issues, there remains a vast amount of data that could, and should, be collected and placed at an accessible repository.

Establishing such a repository is a mammoth task. It requires answering questions such as:

- Where should the repository be?
- Who should fund it?
- Who should manage it and how?
- What should the general framework be for reorganizing existing data and collecting new data?
- What should be the best form for accessing the data bank?

The Data Repository is a task that should be initiated without further delay. We recommend HUD establish immediately a Task Force to examine and prepare recommendations regarding the issues shown above.

b. Performance Requirements - Develop performance requirements including quantification and standardization of performance expectations as well as performance requirements for the introduction of new materials in construction projects.

There is a worldwide move toward the development of performance-based engineering concepts and procedures applicable to the design and construction of commercial buildings. The application of such concepts to residential construction has been slow, except in the area of earthquake-resistant design. In contrast to the prescriptive design approach, typically described in building codes, the performance-based approach provides a more rational design with the built-in flexibility that can accommodate different levels of needs of the owners, while maintaining a defined level of safety.

Quantifying performance expectations for different types of structures performing their intended functions under different conditions is difficult. The extent to which such performance can be technically satisfied with our current knowledge in analysis and material characteristics must be determined. This is particularly true when the use of new construction materials would lead to a hybrid form of housing design and construction. This could add a new realm of testing, design, analysis, and construction challenges, and create a new set of quantitative performance requirements for architects, engineers, building codes officials and homebuilders.

We recommend that a task force be established to examine this performance-based approach, specifically its application to residential design and construction, with special attention to the impact on the introduction of new materials. The task force will identify critical elements in performance-based design and develop research projects in an integrated manner. Such integration will result in a solid foundation for the performance-based design approach to houses and construction overall.

c. Defect Study – Study the concept of what is truly and scientifically a "defect." Define what a defect means within a construction project. Collect defect data to quantify defects and their statistical significance. Determine the cause/effect relationship between defects and all aspects of constructed performance, including structure, function, capacity, service life, durability, water resistance, and fire.

The subject of defective materials or processes can be viewed as a subset of the performance requirement issue discussed above. However, the difficulty in defining and finding solutions for the problem requires that the subject be addressed individually. The very first challenge of this subject is how to define a "defect." What is it?

- Mis-aligned reinforcing bar placement;
- Inferior quality concrete placed at the site;
- Uneven seams at the interface of walls built with different of materials;
- Hairline cracks on a finished wall, a column, or a beam; or
- Uneven mortar joints (color or thickness) in bricklaying?

Some defects can impact a house's structural performance. Others may be inconvenient or be an eyesore. From the homeowners' perspective, the latter issues can often be perceived as greater problems than the structural problems. Such problems are often not observed by homeowners due to the nature of the construction. Review of the definition of defect for all situations should be conducted; many of them are already in codes and design guides. How these definitions reflect the actual performance of a structure should be examined. Are there lab and field data to support or dispute such established definitions of "defect?" Should the current definition of "defect" in that sense be discarded, revised, or reestablished? How should we go about doing it? What types of defect data are available? How should we gather and catalog them? Are there existing methods that can be used to establish the relationship between the nature of defects and the performance of a house with such defects? How could we coordinate this effort with the data warehouse mentioned above?

To address these issues, we recommend placing this work as a subtask of performance requirements as performance requirements cannot be adequately developed until it is know what a defect is and how it impacts performance.

d. <u>Contribution of Nonstructural Components to Building Performance</u> - Develop methods, including general analytical models, to study the contribution of nonstructural components to the overall structural performance of construction.

The presence of nonstructural components, such as a non-load bearing exterior and especially interior wall partitions, has been ignored when analyzing the resistance of a building or a house under different types of loads. This traditional design method also serves to account for uncertainties by providing a level of conservatism. By inclusion of non-structural components in the design, and through the introduction of performance-based design, home designers will have a more realistic picture of how resistance of a house is derived from a whole-house based concept.

In addition to testing subassemblies, assemblies, and whole-house systems to quantify the level of contribution from the nonstructural components, models should be modified to incorporate such contributions. While our current practice provides an undefined degree of conservatism by discounting nonstructural contributions, a better understanding will lead to the ability to adjust the level of conservatism depending on the performance requirements that are needed for a particular type of structure. Recently completed full-scale testing of wood-frame houses subjected to seismic loads, as part of the Earthquake Hazards Mitigation of Woodframe Construction program carried by CUREe after the 1994 Northridge Earthquake in California, has begun to shed some light on this issue.

Evaluation of the structural contribution of nonstructural components could be initiated by a separate task force, or by a sub-task group under the "performance requirements."

e. <u>Technology Transfer to End-Users</u> – Develop and/or expand on existing tools and work with current industry groups with on-going knowledge/expertise to implement technology transfer of any new technology created to end-users of this technology.

As mentioned in the beginning of this report "PATH is a partnership between the public sector and the home building industry dedicated to improving new and existing American homes by **accelerating the diffusion of technologies into home building,**" and also to reducing property losses to homeowners. This statement underscores the critical role of technology transfer. It speaks the sole reason for the nation's housing technology program, which is to help builders adopt new and appropriate technologies.

While technology transfer to builders is an issue of ultimate importance, it is also one of the most difficult problems to solve. Many reasons have been cited. They include:

- A general lack of system engineering and analysis in the design and construction industry,
- The question of who is driving the housing market – the consumer or the homebuilding industry,
- A labor force which frequently resists change,
- The regulatory processes,
- Builders' lack of control of the home building process,
- Industry fragmentation,
- Industry's resistance to change, and,
- Builders' resistance to change.

A task force should consider, taking into account the many technology transfer activities already taking place within industries by associations and proprietarily by companies, how technology transfer could be enhanced and how to assist in improving the flow of information to the field.

5.4 Relationship of the Priority Topics to the Three Roadmapping Areas

While each of the five R&D priority topics focused on one particular area, accomplishment of all five of them could help accelerate the realization of many of the goals in the Roadmaps. The following table shows how they may be related to the three Roadmapping areas.

Table 5.3 Priority Topics as Input to the Roadmapping Areas

Recommended R&D Activities	PATH Roadmapping Areas						
	Information Technology	Panelized-type Systems	Whole House & Building Process Redesign				
			1	2	3	4	5
Data warehouse	●	●	●	●	●	●	●
Performance requirements		●	●	●	●	●	●
Defect study		●			●	●	●
Contribution of Nonstructural components			●	●	●		
Technology transfer to end-users	●	●	●	●	●	●	●

Whole House Roadmapping Areas:
1. Accelerate acceptance of innovative home building technologies: Manage the change process.
2. Create an environment in the home building industry that facilitates systems solutions: Change the paradigm.
3. Industrialize the home building process.
4. Improve the constructability of houses.
5. Move more of the home building process into the factory.

Specific timelines for each of the R&D topics are not presented because of the broad nature of the R&D topics, as opposed to specific tasks. All of these prioritized R&D topics can, and should, be supported even at a time when research funds are limited. Funding agencies should consider them as priorities when making funding decisions on individual proposals. Efforts should be made to explore joint-funding possibilities as well as involvement of the private sector. Support for these R&D topics should start immediately.

5.5 Role of the Federal Government

Discussion of the role of the Federal Government during the workshop was limited. While participants recognized the amount of Federal funding for this R&D area has been modest, they acknowledged it represents the single largest contribution. They recognized the Federal Government could perform a useful role in this undertaking. The participants indicated they would like the Federal Government to place a low priority on R&D that would result in the development of new materials, and new structural systems, e.g., wall panels; such developmental efforts should be the responsibility of the private sector because of the potential market implications of such R&D efforts. However, the participants felt the Federal Government should support the effort to set targets for new product development, establish test protocols, and support the development of modeling capability. They recognized a need for collaboration of some of these R&D activities. But how that could and should be done was not specifically discussed at the workshop and is a topic worthy of in-depth discussion so that everyone understands the mission of the government and the mission of industry in this arena.

Discussion of which Federal Agency or agencies should coordinate these R&D activities was brief, due to the lack of time. While each of the agencies at the workshop (DOE, HUD, USDA/FPL, DOC/NIST and FEMA) has its own housing technology related program, each agency's program also has a special focus. For example, the DOE program focuses on energy efficiency and, in conjunction with EPA, green technology. FEMA focuses its effort on the performance of the housing stock under extreme conditions as imposed by natural disasters. FPL/USDA focuses its effort on bettering the performance of wood-product housing technology. NIST focuses on specific technical areas that match the personnel and facilities.

HUD, as part of its mandate to develop affordable housing technology through its regular R&D program and PATH, has been given the opportunity to address all aspects of housing technology needs, through its long-standing partnership with the private sector, especially with the NAHB Research Center, and recently through joint support of many projects with other agencies, including those mentioned above, plus NSF. This could place HUD in a position to be the coordinator to facilitate the R&D process.

SECTION 6. CONCLUSIONS AND RECOMMENDATIONS

The PATH goal is to improve housing affordability and value through focusing on the cost, durability, energy and environmental efficiency, disaster resistance and safety of homes. It sets specific goals that the PATH program will meet by 2010. The objective of PATH technology roadmapping is to identify technologies that can, in combination, allow the home building industry to achieve the PATH goals.

This report defines the research and development needs for structural performance of light-frame residential construction. Five prioritized topics were identified at the July 2001 workshop. They are: data warehouse, performance requirements, defect study, contribution of nonstructural components, and technology transfer to end-users . Successful execution of these recommended activities will help facilitate meeting some of the goals in each of the three-roadmapping areas.

The role of the Federal Government in this very focused R&D effort was not specifically addressed at the workshop due to lack of time. However, the workshop participants' view about this subject became quite clear through their discussions on how R&D efforts of some of the topics should be carried out. Participants felt that the Federal emphasis in support of R&D should be in the area of targets for new product development, development of test protocols, and support for improved models. The actual development of products and materials should be the responsibility of industry.

HUD, as part of its mandate in support of the nation's R&D to develop affordable housing technology through its regular R&D funding and through the PATH program, has been given the opportunity to address all aspects in housing technology needs, especially through its long-standing partnership with the private sector through the NAHBRC, and recently through joint support of many projects with other agencies. This mandate could be placed upon HUD so that there is a coordinator that is responsible for facilitating the coordination gap in the governmental R&D process..

Appendix A

Recommendations and Directions from the Background Report

Structural Loads

- Near surface wind speed measurement – To collect near surface wind speed to advance modern house design and construction. This may include the development of a realistic wind speed map.

Structural Resistance

- Measurement of load path – To help develop a comprehensive analytical model to determine the distribution of forces and displacements throughout the system.

- Modeling and testing of wall and roof systems – To focus on durability and compatibility of building components.

- Development of new and renewable materials – To reduce or eliminate waste and protect the environment.

- Development of prefabricated wall panels – Successful design and application of such panels in residential construction will increase quality, construction efficiency, and energy efficiency; and reduce construction cost.

- Light gauge steel testing and modeling – Current use of light gauge steel in housing construction follows the same prescriptive method as established for wood. This R&D is needed to take the full advantage of the strength characteristic of steel.

- Laboratory testing and modeling of connections(including anchor bolts) – A systematic evaluation of various types of connectors should be carried out under uniform testing conditions to determine their effectiveness.

- Full scale testing – Such testing should focus on the development of means to maintain the integrity (the enclosure) of the whole house. This is particularly critical when it comes to winds because the enclosure takes and transfers the effects. When the enclosure fails, rain or moisture enters the envelope and causes the bulk of the damage.

General

- Development of instruments and instrumentation – To develop portable, rugged, yet inexpensive anemometers for near surface wind speed measurement. To develop methods for conducting non-destructive tests to determine the engineering characteristics of the materials used in existing houses.

- Development of performance-based engineering standards – There is a worldwide move toward the development of such standards. In US, the emphasis has been seismically based. However the issues and implications for building practices are much broader and therefore the "performance-based" approach should be addressed from a broader perspective.

- Collaboration among researchers – Tackling a complex system such as a light-frame structure requires a team effort. Collaboration among researchers is no longer desirable, but a necessity. Collaboration avoids duplication, optimizes utilization of expertise and financial resources, enhances intellectual exchange, and help forge strong bonds among researchers.

- Need of a national program on wind disaster reduction – Such a national program is overdue. A recent effort between a bi-partisan Wind Hazards Reduction Caucus in Congress and a Wind Hazards Reduction Coalition in the private sector is now underway to push a "wind" bill through Congress.

Workshop on R&D Needs for Structural Performance of Light-frame Residential Construction
Virginia Tech, Falls Church Campus
Tuesday, July 24, 2001

A G E N D A

8:30 a.m.	**Welcome Remarks**	Kirk Grundahl, PE Executive Director Wood Truss Council of America
8:35 a.m.	**Opening Remarks**	Bill Freeborne, PE Senior Research Engineer Division of Affordable Housing Research Department of Housing and Urban Development
8:40 a.m.	**Goal and Tasks of the Workshop**	Carlos Martín, PhD Senior Research Engineer Moderator

Goal: Develop a research and development strategy to enhance performance of light-frame residential construction.

Tasks:
a. Identify the critical research and development needs to understand structural performance.
b. Recommend how needs can be satisfied and information gaps can be filled.
c. Describe the role of the federal government, particularly HUD's, in implementing strategy.

8:50 a.m.	**Review of the Background Report**	Riley M. Chung, PE, Ph.D
9:20 a.m.	**Instructions on Concurrent Sessions**	Carlos Martín, Moderator

Two concurrent sessions are planned; participants will be assigned in advance to achieve a balanced representation. Recommendations from Background Report can serve as starting points. See attachment.

9:30 a.m.	**Break**	
9:45 a.m.	**Sessions A and B**	Session Chairs
Noon	**Working Lunch**	
1:00 p.m.	**Sessions A and B**	Session Chairs
2:00 p.m.	**Recess** *Reporters consolidate workshop findings and recommendations.*	
2:30 p.m.	**Presentation of Workshop's Findings and Recommendations**	Carlos Martín, Moderator

The findings and recommendations will constitute the workshop report that will be offered for the participants' review before being finalized. HUD will mail the final report to all participants and make it available on the PATH web site.

3:00 p.m.	**Closing Remarks**	Andrea Vrankar, PE, RA

APPENDIX C
Attendees

Workshop on R&D Needs for Structural Performance
of Light-frame Residential Construction
Virginia Tech, Falls Church Campus
7054 Haycock Road
Falls Church, VA 22043
Tuesday, July 24, 2001

Attendee List

SESSION A

Dana Bres, US Department of Housing and Urban Development
Riley M. Chung, Millennium Technology Consulting International
Charles Clark, Brick Industry of America
Jay Crandell, NAHB Research Center, Inc.
Habib Dagher, University of Maine
Bradford Douglas, American Forest and Paper Association
Mark R. Fortney, Penn State University
Dave Gromala, Weyerhaeuser
Kirk Grundahl, Wood Truss Council of America
Bo Kasal, North Carolina State University
Ed Laatsch, US Federal Emergency Management Agency
Carlos Martin, US Department of Housing and Urban Development
Richard Mendlen, US Department of Housing and Urban Development
David Rosowsky, Oregon State University
Alex Salenikovich, Forest Products Laboratory, Mississippi State, MS
Emil Simiu, National Institute of Standards and Technology

SESSION B

Mike Baker, Trus Joist, A Weyerhaeuser Business
Jim Cheng, State Farm Insurance Companies
J. Daniel Dolan, Virginia Polytechnic Institute and State University
Eileen Faulkner, Aspen Systems Corporation
William Freeborne, US Department of Housing and Urban Development
Charles W. Graham, Texas A&M University
Kelly J. Gutting, Truss Plate Institute
Emanuel Levy, Manufactured Housing Research Alliance
Philip Line, American Forest and Paper Association
Scott Locklear, American Forest and Paper Association
Jason McJury, US Department of Housing and Urban Development
Cheryl O'Brien, Idaho National Engineering and Environmental Laboratory
V. Ramakrishnan, South Dakota School Of Mines And Technology
Paul Tertell, US Federal Emergency Management Agency
Arun Vorha, US Department of Energy
Andrea Vrankar, US Department of Housing and Urban Development
Cynthia D. West, Forest Products Laboratory, Mississippi State, MS
Tom Williamson, The Engineered Wood Association

APPENDIX D

SUMMARY OF DISCUSSION AT THE WORKSHOP

The concurrent sessions took two distinct approaches to their task.

In Session A, the group first explored the following questions:
- What do we know?
- What do we have left to know?
- What should we be doing?
- How should we be doing it?

The group focused discussion on four topic areas: structural loads, performance, materials and construction, and general and institutional perspectives.

Session B's discussion used the list of topics from the *Recommendations from the Background Report*, which was distributed as part of the workshop information package (Appendix A), as the starting point. The group nevertheless expanded the categories to include the following main topic areas: structural loads, structural resistance, technology transfer, and general.

The following summary presents the discussions of each of the topic areas in two categories: observations and research requirements. The author developed a lead paragraph before introducing a consolidated list of discussion statements for that specific topic. These topic areas are:

- Structural loads
- Structural resistance and performance
- Design
- Testing of construction materials
- Construction materials
- Construction quality
- Durability and life cycle costs
- Identification of failure

Three additional areas were added:

- Codes
- Technology Transfer
- Institutional Issues.

1 Structural Loads

The section is presented in three subheadings: General Description of the Load, Special loads, and Information Management.

1.1 General Description of the Load

What to use as the structural load is always the first step in our design; we invariably select load values from a building code. We rarely question the validity of the numbers in the load tables that we have used for many years. Are we accepting what we have been using as a norm? Should we take a fresh look of some or even all of those values that have been used for years to better understand the magnitude of these design loads and their load paths with respect to the most recent development in housing technology?

Some of the discussion points are summarized below:

Loads level and confidence
- There is a lack of good baseline information on loads that houses are experiencing. Such a baseline would help designers better satisfy the actual requirements.
- Define the confidence level on levels of loads – what is the distribution throughout time rather than at one point in time?
- From a building code perspective, the loads that are used to define design requirements are somewhat suspect.

Instrumentation for load measurement
- Suggest industry take the lead in developing general instruments and also conducting instrumentation programs.
- Increase the coverage of sensor nets for residential structures. The current emphasis for instrumented buildings is on commercial, not light-frame.
- Since we are more interested in load levels on buildings, we should instrument the structure with destructive instruments rather than destructive testing of a whole house.

Load measurement in testing
- Need to measure how much stress each of the members in a structural system is taking up.
- Testing of houses at the Forest Products Laboratory (FPL) measures forces, primarily at the truss connections in order to understand the life history of these trusses.

Design Tools
- Develop a set of fragility curves for homes so that we can predict the behaviors of homes to a number of hazards.

A Word of Caution
- For these loads, are we "chasing the final three percent" of the information that will not affect how a building is constructed? Is it just an academic exercise? Or is this research going to make a significant difference?

1.2 Special Loads

Special loads include loads from wind, seismic, flood, and others such as snow, moisture, transportation, vibration, construction, impact, fire, and bio-degradation

Wind

To many designers and for many years, wind forces acting on houses have been a difficult topic. Too many factors and too many approaches have been flooding this technical topic: return period, maximum wind of the fastest mile, height of wind speed measurement, boundary layer effect – the amount of reduction, wind directional effect, local buffering effect – e.g. such as by terrain, by corner configuration, roof configuration, and others. Practitioners have complained about the complication of the ASCE-7 but researchers continue to refine what is in the ASCE-7. Where is the balance? The lack of a rugged and reliable instrument for wind speed measurement during severe wind events is yet another issue. We simply do not have a good database for wind speed from past windstorm events. Such information is needed desperately.

House Damaged by Wind
- Wind damage estimates are more geared to one-time maximum load rather than cyclic loads.

Wind Load and Its Measurement
- Most wind loads are based on an extrapolation of wind speeds above 30 feet from the surface. As a result, many buildings are significantly stronger than is actually required. By understanding the actual wind loads, we may be able to make significant savings in home construction.
- For wind loading, we need to be able to know what the wind speeds are. We need to know the aerodynamic loads on the structure, a combination of the configuration of the structure and the wind.
- Collect near surface wind speed. Or specifically suggest collecting wind speed data at eave height, not just at 30 feet.
- Use the return wind speed approach. But we need to know more about load definition per return period.
- Florida Power and Light and Texas A&M University are negotiating a contract to study wind loading below 30 feet.

Balance between Research and Application
- Keep the research efforts on wind speeds, wind fluffing, etc. practical for housing application. Keep it simple. Don't make it look like ASCE-7.

Laboratory and Field Testing

- Texas Tech has done full-scale tests on a manufactured home using a C-130 aircraft. The tests may have some relevant wind load data for light-framed structures.
- Study the loads on the thermal envelope as a result of the wind loads or other structural loads on the house, especially the cyclical loads.

Evaluation of Buffering Effect

- There are no good models for the local buffering effect from wind loads, but only generic wind load models. There is a lot of information on this topic.
- Clemson has been looking at buffering effects of cyclic wind loading on the roof system.
- Evaluate the effects of terrain, different corner configurations (rounded etc., deflectors, and spoilers), hip-roof performance, aerodynamic effect of a whole house including winds below crawl space, and fluttering on the underside of the structure.

A Word of Caution

- How a building is constructed has a huge impact on the performance of a building under wind loads. Poor construction results in poor performance. Is this just an academic exercise? Or is this research going to make a significant difference and actually deal with real performance on buildings properly constructed? Are we going to deal with the symptom or the problem, which means dealing with construction quality first?

Seismic

In the past, most research on seismic resistance has been focused on the performance of large reinforced concrete, masonry, and steel-frame structures. Following the 1994 Northridge earthquake that devastated the Los Angeles region, research supported by FEMA and the State of California, has begun to include seismic performance of residential construction. But the workshop participants felt many aspects of the seismic design of houses have been neglected by the current effort. Some of their concerns are given below.

Earthquake Damage

- It is typical to see a structure experience a degree of failure prior to catastrophic structural failure due to the cyclical nature of failure.

Poor Correlation between Design and Performance

- Information on how a building performs during a seismic event is poorly correlated to the design. Currently, the scatter on the information is so bad that performance cannot be predicted.
- At present, seismic design provisions control much of the design process, even though they may not be the biggest issues facing the performance of a house.
- We need to develop a set of better seismic design parameters that relate to actual light-frame performance. In the past, we have not been able to correlate the damage to homes to the actual accelerations seen, or predicted, in the field. Perhaps we should abandon the way we currently approach seismic design and develop a new approach.

Manufactured Houses

- Examine how manufactured houses perform during seismic events. Results should have particular interest because the structure is integrated.

Effects of Nonstructural Components

- Study the effects of seismic loads and stiffness on non-structural components. These components can greatly affect the load path as well as stiffness. Currently these effects are ignored.

Codes and Inadequacy in Codes

- In South Carolina, the 2000 IBC was reported to prevent use of a brick veneer higher than one story. This has already impacted the brick industry.

A Word of Caution

- How a building is constructed has a huge impact on the performance of a building under seismic loads. Poor construction results in poor performance. Is this just an academic exercise? Or is this research going to make a significant difference and actually deal with real performance on buildings properly constructed? Are we going to deal with the symptom or the problem, which means dealing with construction quality first?

Flood

Losses due to flood occur every year and generate the greatest claims in insurance and in disaster relief funds in America. However, because the government underwrites flood insurance, research on this hazard is underserved. What are the flood loads? How do we measure them? How do we design against flood loads? Some issues brought up for discussion were:

- Study the effect of impact load from waves.
- Need flood data relating to the effects of scour and erosion in coastal areas. What is the resistance to wave impact or surge loads? What is the performance of flood resistance building materials?

Others

Other loads include loads from bio-degradation, construction, fire, impact, moisture, snow, transportation, and vibration. Often these are regional issues that are not being addressed on a national level. For example, in Maine, the hazards are not wind or snow loads, but ice dams.

Bio-degradation
- Study bio-degradation loads in general which include: mold, solar (UV), fungus, pests, etc. However, such loads seem to be material specific. Solutions for such problems frequently will require an interdisciplinary approach.
- Develop design values for loss of strength values due to bio-degradation from laboratory tests that would simulate what may occur in the field. Collecting field performance data due to bio-degradation is a long-term process. Because such effects may not be totally predictable, they cannot be addressed in the code.

Construction
- Study loads on houses experienced during construction such as those due to temporary bracing, truss placement, etc.

Fire
- Study fire loads on houses due to forest fires, range fires, etc.
- There is an inorganic paint that would protect wood up to 1000^{o}F. This seems to be a problem interesting to the industry, but has lower priority in the house design and construction community.

Impact
- Study impact loads such as from hail. House damage due to hail is significant. The Federal government should support the development of a test protocol.

Moisture
- Study the moisture loading, the effect of time on wood and the changing moisture levels, especially with respect to wood-frame construction, moisture degradation, and effect on the life-cycle structural performance.

Snow
- Study of snow loads.

Thermal Expansion
- Thermal expansion, i.e., shrinkage and swelling, needs to be addressed. This is a separate issue from moisture.
- Study the cyclic loading due to shrinkage and swelling.

Transportation
- Study loads due to transport of manufactured housing as well as prefabricated housing components or modular homes. These houses experience the greatest loads during transportation.

Vibration or Low Cyclic Effects
- It is not common to see failure due to fatigue in the field but cyclic failure is frequently observed in the laboratory.
- Computational capability must incorporate loads due to vibration, which is different from dynamic loading.
- Study the accumulated cyclic effect on light-frame structures. The effect of repeated loading, or fluttering, on a structure is often more destructive even at lower loads than an ultimate load.

1.3 Information Management

Information management in terms of collection, cataloging, retrieving, and accessibility by users is one of the most urgent issues that need to be addressed. Government agencies as well as some universities and private entities already have a great deal amount of information. Insurance consortia, IBHS, for example, has begun, to look at the loss data from insurers. They were able to identify six or seven data fields. The file now contains about 75 million records.

- Need to establish a repository for information on the behavior of structures during natural disasters as well as during normal conditions. HUD should collect and warehouse the data.
- Develop a data warehouse for loads, performance, etc.
- Need to collect structural wind load data at less than 30 feet.

2 Structural Resistance and Performance

Structural resistance and performance is a very broad topic that encompasses a number of subjects that need to be addressed. The top issues must be identified that will provide the greatest benefit. We should also discuss what are the areas that are "broken," instead of optimizing those that are performing well.

Performance-based Approach

- Develop performance-based engineering standards.
- What is the value to the industry of performance-based design?
- There is no description on the levels of performance that is consistent across the U.S. We could create levels of performance such as "basic performance," "better performance,' etc.
- A minimum performance standard is very difficult to secure because there is simply too much variance in wood/truss material across the U.S.
- Develop analytic models for performance-based standards applying to mixing materials, non-structural elements, etc. that would result in a consistent and rationale basis for the building code. This should be a significant Federal government effort.

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Modeling and Testing

- There is no comprehensive model currently.
- Model and test the performance of construction systems, including wall and roof systems.
- Develop non-proprietary residential-scale seismic testing for concrete industry. The industry now lacks such data because all are proprietary.
- Develop prototypes on full-scale testing that cover more than one system. For a building subsystem, there is no protocol for full-scale testing. For example, you can test a foundation in the field, but there is no protocol for doing it.
- Test shear wall with steel studs utilizing manufactured housing connections such as pins, straps, etc.
- When focusing research needs, we should focus on whole-house performance and construction (monocoque) rather than material-specific research.
- Application testing for residential rather than utilizing commercial-scale testing specifically for fiber reinforcement in concrete that will reduce installation costs.

Contribution of Nonstructural Components

- Study the impact of interior non-load-bearing walls and other non-structural components.

Retrofit Technology

- Research for retrofit and repair of existing houses to avoid future damage – loss exposure is still high.

On Structural Resistance

- When we discussing structural loads they are consistent for any material. But when discussing structural resistance, we should take material strength and flexibility into consideration.

3 Design

Most of the discussions on this topic began with philosophical statements, often addressing the lack of coordination, or authority for quality control, and execution when a project moves from design to construction. For instance, one participant indicated that "We have two issues here: one is engineering or design and the other construction. Often the design is getting diluted as it goes into blueprints (codes, etc.). We then lose control during the construction process. There should be a clear quality control path from engineering through design to construction."

Others argued that we can't enforce the design but can provide incentives to build to a certain criteria (e.g., Energy Star, insurance companies' incentives, etc.). We could provide technical and educational information to the public as well as to builders to help prevent damage (such as moisture, termite, etc.).

- We are short of field test data in many areas which can accurately predict what will happen and to what extent. Such information could then be used to refine design models.
- Timber frame know the right ways and wrong ways to attach timber. Have we adopted these practices to light-frame construction?

4 Testing of Construction Materials

A lot of discussions focused on the merit of full scale testing, others on the need for manufactured housing due to the increased popularity of the improved quality and style of such housing design and construction.

Full-scale Testing

- Full-scale testing is expensive and very limited, it is also very important.
- Even though full-scale testing is often limited to few or even one sample, it is still good at confirming other analytical tools and models.
- We don't have much in the way of full-scale testing. For instance, in the BlueSky project in North Carolina the project instrumented a house waiting for hurricanes to come through. CUREe and manufactured housing are the only areas where full-scale testing research is available in the US.
- An international effort on testing and modeling of the "Performance of Whole Building" is being carried out.

Testing

- Laboratory and field tests should be conducted on ancient building materials and methods such as straw-bale, adobe, etc. These materials are now being commonly used in expensive homes and yet there is no information available on load paths, or performance tests such as performed by a shake table.
- Test roof materials to predict and improve roof system performance.

Manufactured Housing

- Test steel framing.
- Manufactured homes often float away in floods due to the failure of tie-downs in saturated soils. Tests should be conducted on their foundation systems including tie-downs.
- Actual ultimate load performance (resistance) of anchor bolts is ill defined. The safety factor is not consistent in the codes when they specify design loads required.

5 Construction Materials

Development of new construction materials and their application by builders through a system engineering approach seemed to dominate the discussion here. It is also here that the participants expressed strongly that development of new materials is in the realm of manufacturers, not the Federal government. The Federal government instead should provide target for the development, as well as to help set up test procedures and protocols and performance specifications. All these would help promote the use of new materials by builders in their construction. If the Federal government did all these things, there will be many manufacturers coming out to develop new materials for cheaper costs.

We should conduct specific research without creating a super family of wood products (such as expensive engineered products which replace less expensive dimensional lumber) because the builder is not going to pay for it unless the insurance and financing agencies pay for it and provide incentives for their use.

Aging and green building technology were the other two subjects prominent in this discussion.

Test Protocol

- We have been seeing many failures in the building materials area, even though we have tried to model the performance of these materials on computers, laboratory, and through field testing before introducing them to the market. The problems seem to be in the testing procedures and protocols and the incompatibility between full-scale and less than full-scale testing. What are the relationships and how do we move from one testing level to another?

System Engineering Approach

- Develop and test materials as part of a system to demonstrate the interaction of different products to demonstrate how the new product will affect the whole system.
- Develop new materials and systems that are more tolerant of construction errors.

Aging

- Include weather effects in the testing protocol, i.e., design it with the understanding that it is going to fail.
- Study new material's accelerated aging process in terms of change in failure mechanisms, systems, and its compatibility with existing materials (e.g., EIFS created havoc on OSB or vice versa).
- Study material durability to understand the time effects on materials as the structure ages. Develop an analog system to present durability, rather than a pass/fail system, therefore allowing product manufacturers to select where they will operate on the durability scale. Evaluation criteria should be developed in a public/private manner. The actual product development should be performed only by industry. The development of metrics should be developed through a public/private partnership.

Green Building Technology

- Rising cost and customer demand now drive the issue of "disposal of waste" high on the agenda of housing construction.
- People are now willing to pay more money for green, renewable materials but it is not clear how much more they are willing to pay.
- Establish a Formosan termite test site.
- Continue development on BEES and LEED models on green and sustainability.

6 Construction Quality

Good construction quality requires contractor training, education, outreach, and certification. There is no contractor certification process to ensure contractor quality. Years ago there was an apprenticeship program for workers. In the housing industry, such programs are rare today. This has resulted in problems with inconsistent worker qualifications in the housing industry. These are reasons that the participants felt that 90% of the problems occur in the field. Making the things worse is the perception that builders, when discussing quality will state "*That is the way I have done it for the past twenty years.*"

Problem Quantification and Minimization or Avoidance

- Define the problem and help builders understand why the quality issues are important.
- Assess the critical structural quality points that really impact the building performance. For example, builders are using framing quality programs to reduce or eliminate callbacks. Callbacks may be the wrong metric. In many cases, the codes/design may be creating a system that the framer in the field can not achieve. And that is the reason why that such assessment is needed.
- It is unlikely that we will ever be able to train a workforce to avoid all construction faults. Instead, we should introduce the construction problems in the testing and design so preventive approaches can be incorporated into the design.
- The industry should look at building systems that are less prone to construction errors in the field. For example, develop prefabricated wall panels to reduce the reliance on the workmanship of the field personnel.
- It was also suggested that this area should be broadened to include the whole structural system. That is, to take a system and factory approach to solving the integration problem as seen in modular and manufactured housing.
- Quantify the nature and extent of construction errors and their occurring frequencies on structural performance and quantify building performance expectations.

Insurance and Economics

- We need to show how quality issues are tied to cost. That is, well-executed design and construction should enjoy a financial incentive because the risk is lower.
- As an example, it normally costs $20,000 to frame a typical home or about 10-11% of a total home cost. How important is this issue with respect to the overall structural performance of a house? We should develop economic incentives when selling a good framing structure to builders. However, a typical builder would "kill" to save $20.

- Insurance business is based on risk. They aggregate the total loss for an area, but do not know the actual costs. The only organizations that can fix quality problems belong to the mortgage industry. The day homebuyers stop buying homes because they can't get a mortgage, quality or design problems will fix themselves.

Other Statements

- The truss industry did not have any idea how valuable the process of gathering the quality data would be and when it undertook this work, it became apparent how much the industry did not know and that really helped make industry improvements.
- There is a significant amount of work ongoing on construction quality in framing. However, we overlooked the foundation quality, which is of critical importance.
- There is a big disconnect between the fragility curves and the guy driving the nails – this example highlights the disparity between research and application.

7 Durability and Life Cycle Costs

Recently, some builders and manufacturers have become more sensitive to the economic life cycle rather than just the first-cost. Life cycle cost should consider structural, energy, insurance, mortgage, maintenance, and repair. It should also note that cost of materials is not as important issue to the remodeling sector as to the new construction sector. A major challenge here that needs research is to develop incentives to promote the life cycle cost concept to more builders, manufacturers, and consumers. Builders may need to increase their efforts to educate consumers.

8 Resistance by Existing Housing Stock

Retrofit of existing houses perhaps imposes an even more difficult challenge than the design and construction of new houses. Do we have a good understanding of how the existing housing stock will behave? We should, since it impacts how cost-effectively we could retrofit these existing houses. While the workshop participants did not focus on technical issues often related to how to improve the structural performance of existing houses, they nevertheless brought up some interesting research topics related to "Decay."

- Decay potential map in building codes was originally developed by FPL. FPL is now looking at the accuracy of the map and will update it based on current climate map.
- Australia is also working on a new decay potential map.
- University of California, Berkeley, is working on a new map of fungal growth.
- DOE is currently developing a dynamic moisture model called a hygro-climatic model. Fifty sets of data are now available including rain data that would allow checks on whether a wall system will dry out or not. DOE is also conducting laboratory and field tests to provide information for the model.

9 Identification of Failure

There is no good model for estimating the number and severity of construction errors. Such errors are closely tied to the causes of failures, both failures that prevent houses from performing intended functions and failures that may cause property loss and even loss of life. In the latter case, we often miss the cause and effect relationship. When looking at insurance the focuses is on consumer satisfaction. And as a result, we often overlook other factors that contribute to the problem. For example, while 75 per cent of bricks produced in America are now used as veneer application in residential construction and are not load bearing, often the bricks are blamed for the cracks in a wall and may be repaired following a seismic event, without regard to whether the cracks were preexisting in the load-bearing part of the wall system.

10 Codes

Building codes dictate the state of practices in the United States. Changing the codes is a time-consuming process from research on new technology and material development to be included in the body of building codes. It is not surprising that such process could take up to 12 to 15 years. Further, current building codes do not describe what the performance requirements are. They only define the minimum requirements. As an example, as mentioned in Section 7.1.2, the 2000 IBC states that in South Carolina the seismic requirements prevent the use of a brick veneer higher than one story. The problem with the case on brick veneer is the difference between a prescriptive code versus a performance criteria. From a technical standpoint, the latter is a better process.

Without a performance-based code, it is also much more difficult to introduce new products and methods into the market place.

11 Technology Transfer

Technology transfer is an issue that must be tackled in the context of federal research if research is to have the effect on the housing stock that we envision. Our current state is that we do know how to design and construct houses but what is needed is to educate builders/framers on the proper installation. It is of paramount importance that we develop such educational programs for builder/framer training. All forms of communication should be explored and work should be integrated with existing certified contractor and related educational programs.

12 Institutional Issues

This is particularly a problem for an extremely fragmented industry like the housing design and construction industry. The desire for collaboration among researchers is further dampened by the fact that funding in this area has been inadequate in the past. Unless it is necessary due to the nature and scope of the research, or as a condition for getting a grant or contract, in most cases researchers would prefer to work independently. This is done to reduce the level of competition for future grants. In some occasions, such as the development of new materials, developers obviously would prefer to spend their own funds to keep the product proprietary, therefore enjoying the potential advantage in the marketplace.

Recent trends show that more research topics require an interdisciplinary, team oriented approach, because of the ever increasing complexity of the topic. The Federal government, as the nation's largest funder for R&D, can be in the best position to help facilitate the collaboration among researchers and can change the current practice in conducting R&D.