Wood Engineering Challenges in the New Millennium

Critical Research Needs

Editor
Vijaya K. A. Gopu

SEI STRUCTURAL ENGINEERING INSTITUTE ASCE

ASCE AMERICAN SOCIETY OF CIVIL ENGINEERS

Front cover photos taken by Dr. Rakesh Gupta --- Construction detail for a residential structure in high wind region; Six-story woodframe building, tested as a part of NEESWood research project in Miki City, Japan in July 2009; World's oldest wood structure - A Japanese Temple in Horyuji, Japan.

WOOD ENGINEERING CHALLENGES IN THE NEW MILLENNIUM

Critical Research Needs

Proceedings of the Workshop
Offered in conjunction with the
SEI / ASCE Structures Congress 2008

Pre-Congress Workshop
April 23-24, 2008
Hyatt Regency Vancouver
Vancouver, BC, Canada

Editor: Vijaya K. A. Gopu
Assistant Editors: Rakesh Gupta and John van de Lindt

WORKSHOP STEERING COMMITTEE

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FP Innovations

Ms. Karen Martinson
US Forest Service, Forest Products Laboratory

Dr. David Rosowsky
Texas A & M University (currently at Renssealer Polytechnic Institute)

Mr. Tom Williamson
APA – The Engineered Wood Association

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PREFACE

ASCE Committee on Wood Research organized a one and a half day workshop on ***Wood Engineering Challenges in the New Millennium – Critical Research Needs*** with the support of USDA Forest Products Laboratory. The primary objective of the workshop was to provide a forum for state-of-the-art review and to develop a prioritized research agenda for future wood engineering research. The research needs that support the national/global research drivers, namely, Sustainability, Economic Competitiveness, Health, Life and Property Protection, and Infrastructure Renewal were identified The one and a half day workshop was held in conjunction with the ASCE Structures Congress and began on the morning of Wednesday, April 23, 2008 -- the day before the Structures Congress – and concluded by mid-morning on Thursday, April 24th.

Invited authors prepared position papers covering a wide spectrum of wood engineering topics for distribution to the workshop attendees prior to the workshop. Besides the preparation of the position papers, the workshop involved three specific set of activities described below:

> Activity 1: Two distinguished speakers kicked off the workshop with two keynote presentations. The first presentation dealt with the global research drivers and was delivered by Dr. Ian de la Roche, President and CEO of FP Innovations, Canada. The second presentation addressing the drivers for wood overall—economic impact, resource base, status of research and national research capabilities, and global competitiveness—was delivered by Mr. Ken Skog, Project leader for Economics and Statistical Research Unit at the U.S. Forest Products Laboratory. These presentations set the stage for the ensuing group discussions.
>
> Activity 2: Working groups were organized to establish specific research priorities. Workshop participants were assigned to working groups based on their background and interest and each working group had a balance of researchers, practitioners and industry/code-agency representatives. Each group was lead by a facilitator who provided a summary report to the attendees at the closing session of the workshop.
>
> Activity 3: A committee comprising of some of the steering committee members developed a set of broad-based research initiatives. The final product of the workshop is this proceedings published by ASCE.

Before the workshop, all participants received position papers prepared by invited authors on eight key research areas related to the national research drivers. Workshop participants were heavily engaged in establishing specific research priorities related to the national research agenda. Each participant had the opportunity to be involved in three breakout sessions dealing with research areas of most interest to him or her. This proceedings shows both the need and relevance of wood engineering research in an era of major technological developments.

This workshop was third after the first one held in 1983 and the second one was held in 2007. All three workshops were successful in terms of attracting wood researchers, users, and practitioners. The workshop provided a forum for exchange of creative ideas and research needs by practicing engineers, industry leaders, and university researchers. The critical research needs in new millennium have now been clearly well defined. How we go about pursuing these is now a challenge to and responsibility of the wood engineering community.

Vijaya (VJ) Gopu

ACKNOWLEDGMENTS

The financial and administrative support of the following two organizations has made it possible to hold this important workshop and ensure its success.

Structural Engineering Institute, American Society of Civil Engineers
U.S. Forest Service – Forest Products Laboratory*

The advice and assistance of Mr. Michael Ritter in the planning and implementation of the workshop is greatly appreciated. The members of the organizing committee devoted a considerable amount of time and effort in planning the various aspects of the workshop and their commitment to this undertaking is sincerely appreciated. Several members of the organizing committee – Mr. Ronald Anthony, Dr. Steven Cramer, Dr. John van de Lindt, Dr. Daniel Dolan, Dr. Rakesh Gupta, Mr. Erol Karacabeyli, and Mr. Tom Williamson – handled the added task of developing position papers on key areas linked to the global research drivers. I would like to thank them for their extraordinary level of volunteer service to this workshop.

The workshop session facilitators and scribes did an outstanding job capturing the essence of the discussions and prepared the summary presentations that helped the participants gain an appreciation of the important needs in all the areas addressed in the workshop. I would like to express my gratitude for their service.

The success of the workshop hinged on the active involvement of the participants in the various sessions. On behalf of the workshop organizing committee, I would like to express our appreciation for their involvement, contribution to the discussions and the overall success of the workshop.

The support and assistance of the SEI staff members throughout the workshop greatly enhanced the ability of the members of the organizing committee to hold an effective event. Their contributions to the workshop are highly appreciated. I would like to express my sincere appreciation to the ASCE Wood TAC from its support and encouragement in holding this important workshop. The assistance of Drs. John van de Lindt and Rakesh Gupta in putting together these proceeding is greatly appreciated.

Vijaya K. A. Gopu
Workshop Chair

*Any opinions, findings, conclusions, and/or recommendations expressed in these proceedings are those of the authors and no not necessarily reflect the views of the USDA-FS FPL.

GREEN BUILDINGS

POSITION PAPER

GREEN BUILDINGS

Tom Williamson, Fellow, ASCE
APA – The Engineered Wood Association
tom.williamson@apawood.org

Abstract

As Kermit the Frog would say, "it's not easy being green". And the wood industry can say the same thing. While the wood industry understands that wood is a green building material that is not the perception held by most non-wood industry people, especially design professionals. Designing "green buildings" has taken on a life of its own with the promotion and proliferation of green building rating systems. Design professionals want to be perceived as being environmentally conscious, and what better way to achieve that than by being proclaimed a "green building" designer. Some of the buzz words in our headlines are "global warming", "carbon sequestration", "greenhouse gasses" and so forth and these all relate to the protection of our environment. One way to accomplish this is to use more wood in building construction. While wood is used in approximately 85% of the homes built in the U.S., there are increasing pressures by the steel and concrete industries to erode this market share and one of their messages is that wood is not a green building material. Conversely, only 10% of the low-rise nonresidential building area (5 stories or less) is framed with wood and there is a major promotional effort underway in North America to increase this market share. One of the key messages is that, in addition to delivering increased design flexibility, wood is an environmentally friendly building material. With the steel, concrete and wood industries all making different "green" claims, design professionals are left in confusion. What is needed is a scientific basis on which the design professional can evaluate these claims.

Introduction

Environmental attributes of wood are well known within the wood community. Some of these are:

- Wood is the only common structural building material that is renewable. Powered by solar energy collected by a tree's leaves, carbon dioxide extracted from the atmosphere and water absorbed through the tree's roots is converted to cellulose by photosynthesis.
- Wood is composed primarily of hollow cellulose fibers bound in a matrix of lignin. This makes for a very versatile lightweight structural material that is easily shaped with tools.
- In a managed forest, as mature trees are harvested they are replaced by younger trees and the wood resource is renewed. In a well managed woodlot this natural renewal can continue indefinitely as long as there is an ample source of water, carbon dioxide and sunlight.
- Increasing levels of carbon dioxide in the atmosphere, from the consumption of fossil fuels, is a primary cause of accelerated climate change. The adverse environmental impacts of climate change could be catastrophic and there is a consensus in the scientific

community that the carbon dioxide level in the atmosphere is approaching a crisis level. The only practical technology currently available for extracting carbon dioxide from the atmosphere is the cultivation and harvesting of trees and other crops.

- A well managed forest or woodlot will extract a considerable amount of carbon dioxide from the atmosphere. For every pound of wood grown, 1.47 pounds of carbon dioxide is removed from the atmosphere and replaced with 1.07 pounds of oxygen.
- Wood has low embodied energy compared to most other structural materials. The energy consumed in managing forests, harvesting trees, milling timber and transporting lumber to job sites is relatively small. Wood fares well when comparing the manufacturing impacts of building materials such as solid waste generation, air and water quality impacts, and greenhouse gas creation.

So, what is needed to support these wood industry <u>facts,</u> which are often viewed as wood industry <u>claims,</u> to convince design professionals that wood is not only a green building material but the "greenest" building material. Is it research or technology transfer or a combination of both or something else?

Forest Management

As part of the wood industry message it is important that design professionals understand that if a forest is not managed and trees are not thinned and harvested, the forest will mature to a point where carbon dioxide produced by the decay of dead trees and limbs or by forest fires balances the carbon dioxide extracted by new growth. To effectively remove carbon dioxide from the atmosphere on a sustainable basis, mature trees must be periodically harvested and milled into building products that will endure for many decades. This is referred to as "carbon sequestration" since carbon becomes a permanent and integral part of the building products. One key to effective carbon sequestration is building durable structures that will endure for many decades, or even centuries, with wood products.

Forest management has evolved into not just maximizing timber yield, but also protecting streams and rivers, minimizing erosion, protecting natural ecosystems and enhancing wildlife habitats. It is important to maintain a riparian fringe of undisturbed vegetation immediately adjacent to rivers and streams. The vegetated fringe serves as a natural bio-filter that traps nutrients and eroded soil that would otherwise degrade the waterway. The plant roots stabilize stream banks, the tree canopy provides essential shade for the water, and trees fall into the streams to create stream flow conditions important to many fish and other riparian species.

Forests are unique and differ by tree species, soil types, elevation, climate, and terrain. Each forest type requires a specifically tailored management strategy to keep the forest healthy, maximize forest growth, and protect against environmental degradation. Foresters have developed a variety of silvicultural tools to assist them in responsible forest management. The most important aspect of sustainable forestry is keeping forests healthy and available as a long-term resource. When forest lands are displaced by shopping centers or housing developments, the resource is lost forever. Development pressure is by far the biggest threat to forests globally.

So how does a structural engineer know if the lumber on his or her project came from a responsibly managed forest? There are now certification programs for wood products that verify that a particular board, joist, or beam was produced following specific sustainable forestry criteria.

There are four prominent forest certification programs in North America. They are the *American Tree Farm System (ATFS)*, the *Canadian Standards Association (CAN/CSA-Z809)*, the *Forest Stewardship Council (FSC)* and the *Sustainable Forestry Initiative® (SFI)* standards. While there has been considerable debate over which certification program is best, all four are recognized and credible programs. The CSA, FSC, and SFI programs have criteria for certified wood products. All three programs have a chain of custody system for manufacturing facilities to track the percentage of fiber that originates from certified forests. The SFI program is the only system that provides procurement system certification for manufacturing facilities following the procurement provisions in the SFI standard. The North American volumes represented by each are as follows:

ATFS	35	million acres
FSC	71	million acres
SFI	143	million acres
CSA	182	million acres

One of the challenges facing building designers who want to be "green" designers is that the most dominant green building rating system, LEED™, only recognizes one of the forest management systems, FSC, and this limits the available forest resource to about 16% of the total North American certified forests. And this may discourage designers from specifying wood in their green designs because of the lack of availability of FSC wood products.

Green Building Rating Systems

There are three primary green building rating systems in the U.S. These are the USGBC LEED™ system, the GBI Green Globes system and the NAHB Green Building Guidelines.

The USGBC was founded in 1993 and has grown to over 12,000 member organizations. As an example of their influence and growth, of the 606 U.S. cities with a population of more than 50,000 that responded to a recent USGBC survey, 92 have a green program in place whereas in 1997 there were but two such cities-and another 36 have programs in the works.

The mission of the USGBC is to promote buildings that are environmentally responsible, profitable and healthy places to live and work which is an admirable goal.

To help accomplish this, the USGBC promulgates several certification systems to distinguish buildings that have demonstrated a commitment to sustainability by meeting high performance standards and` the most prominent ones are:

LEED™ for New Construction
LEED™ for Existing Buildings (Remodeling)
LEED™ for Commercial Interiors
LEED™ for Homes

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System™ encourages and accelerates global adoption of sustainable green building and development practices through the creation and implementation of universally understood and accepted tools and performance criteria.

But one of the criticisms of the LEED™ for New Construction system by the wood products industry is that it discriminates against the use of wood products as it:

- Does not properly rate products based on environmental criteria
- Does not recognize life cycle assessment comparisons
- Has not been developed in a process not seen as consensus based by all interested parties
- Only recognizes FSC products and not SFI or CSA as certified
- Does not recognize renewability of wood products (renewable defined as a 10 year growth cycle)
- Does not equitably recognize recyclability of products (recycled steel seems to be favored)
- Provides "false" benefit for local manufacturing (based on an arbitrary 500 mile radius)
- Discriminates against some composite wood materials based on UF content rather than on measurable emissions or any other health-impact measure.

An alternative rating system for nonresidential construction is the Green Globes system promulgated by the Green Building Initiative, GBI. The Green Globes rating system was developed in Canada and based on the United Kingdom's Building Research Establishment Environmental Assessment (BREEAM) and introduced into the U.S. in 2005 and is therefore a relative newcomer to the green building rating arena. Unlike LEED™ the Green Globes system is more favorable to wood by recognizing that:

Wood is a renewable resource
Recognizes all credible forest management certification programs
Acknowledges LCA as a method for evaluating environmental impacts
Is developing an ANSI consensus standard for Green Globes to be completed in 2008

For green rating of residential construction, the NAHB has published their Green Building Guidelines for new home construction. This was introduced in 2005 and is being turned into an ANSI consensus standard due to be completed in 2008. Like the Green Globes standards, the NAHB standard recognizes:

LCA as a tool to evaluate various building materials and systems
Recognizes wood as a renewable resource
Recognizes all credible forest management systems

Life Cycle Assessment (LCA)

Some of the basic questions that are asked when evaluating the environmental impact of various building materials are:

Is it a renewable resource?
Does it use resource efficient material?
Does environmental data such as energy consumption and CO_2 emissions exist for the material?

Is Life Cycle Assessment used to analyze product or building?
Are there comparisons of environmental impacts to select best material, building design, etc.?

One of the key tools for determining the impact of a building material on the environment is through life cycle assessment (LCA) often referred to as a cradle to grave assessment. But many criticisms of LCA stem from a lack of understanding the science associated with it, and questions regarding the materials data base that is used to measure, or determine, the life cycle inventory or LCI.

LCA is important because it quantifies how a building product or system affects the environment during each phase of its life: extraction, production, installation, use and disposal (or re-use). There are six spacific measures often referenced in LCA for which quantitative information is specifically available for wood-based products:

Embodied primary energy

Global warming potential

Air emission index

Water emission index

Solid waste

Resource index

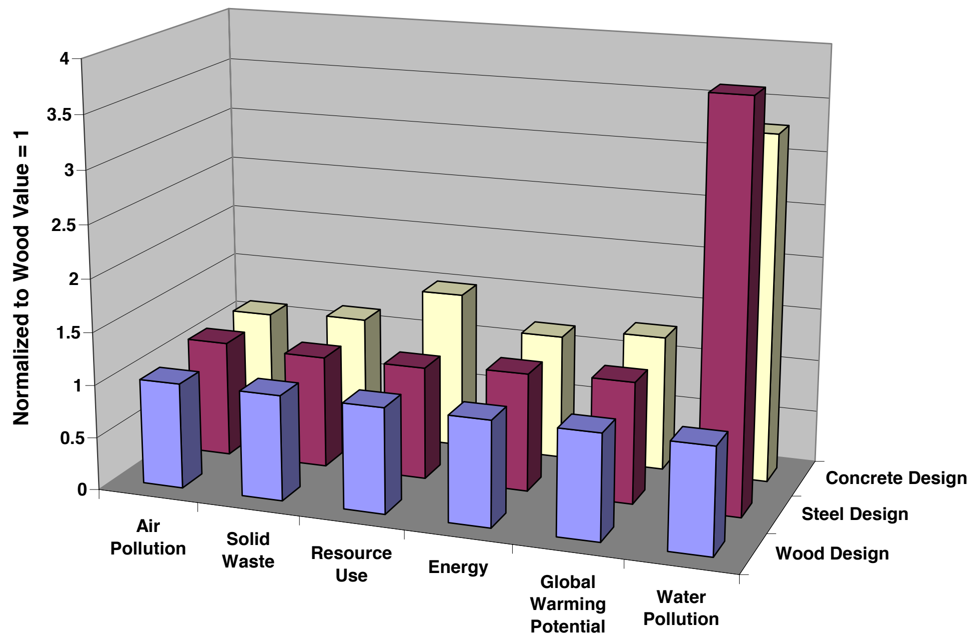
Currently available life cycle assessment tools such as BEES (Building for Environmental and Economic Sustainability) and the ATHENA Environmental Impact Estimator (EIE) can help users to make informed environmental decisions. BEES evaluates the environmental performance of individual products whereas the EIE addresses primarily whole building design.

Energy consumption is one of the most important issues related to sustainable development. Expressed in units of energy (GJ, or gigajoules), the embodied energy of a specific material is calculated by accumulating all of the energy inputs required to harvest or extract, manufacture and distribute a given product or system, as well as energy involved in use and maintenance of the product, and final disposal.

Wood has relatively low embodied energy content because it is "manufactured" by nature using solar energy. A comparatively small amount of manufacturing energy is needed to convert the logs into finished products. Wood is also generally lighter than non-bio-based structural products and therefore requires less energy per mile to transport. Conversely, non-bio-based materials typically use more energy in all production phases: the extraction of the raw material source, the manufacturing into a product and the transporting of a heavy material.

While energy usage is important, the sustainability topic receiving the most attention today is global warming. In this context, the unique attributes of bio-based products provide enormous benefits over other building materials. Substitution of bio-based products for alternative building materials provides carbon-reduction and carbon-sequestering.

Studies also illustrate the advantages of wood products over competing materials in preserving air quality (i.e., lower gas emissions due to harvest, manufacture, transportation, etc), water quality (i.e., lower liquid emissions), and reducing solid waste (i.e., from landfill disposal), as shown in the below.



So, why does the structural engineer need to be familiar with LCA? Building construction, use and demolition is widely recognized as one of the leading consumers of energy and natural resources. In the United States building construction and operation accounts for about 40% of energy use. Building construction and demolition generates more than 123 million metric tons of waste per year, or about 1/2 ton per person per year.

It is often assumed that life cycle impact of a building is dominated by building operation, and that structural engineers have minimal influence on that phase of the building life cycle. Energy use during building operation is the largest component of life cycle energy use (about 85% to 95%). However, as building energy use becomes more efficient, the contribution of the structural engineer related to initial construction and end-of-life demolition will become *increasingly* important. Focusing solely on building energy use also neglects other environmental impacts which are more closely tied to structural engineering. For example, the structure of a building can be a significant part of life cycle impacts related to solid waste generation (up to 40%) and water pollution (up to 60%). Various LCA studies of commercial buildings up to 150,000 ft^2 found that the structural system contributed between 20% and 50% of the environmental impact in some instances.

Perhaps the most critical aspect of sustainable building design is an integrated or holistic design process, which involves interaction of all building design professionals throughout the entire process. Therefore, structural engineers need to understand the basic methodology of LCA so that they can participate more fully in the sustainable building design process and can use LCA to inform and improve their own design work.

CORRIM

The Consortium for Research on Renewable Industrial Materials (CORRIM) was organized to update and expand a 1976 report by the National Academy of Science regarding the environmental impacts of producing and using renewable materials.

Without a scientifically sound database of the environmental and economic impacts associated with using renewable materials, it is difficult for policymakers to arrive at informed decisions affecting the forestry and wood manufacturing industries.

The 1998 CORRIM research plan was designed to develop a scientific base of information relating to the environmental performance of wood based building products. The plan identifies several factors that can affect the efficient use of energy and materials in building materials manufacturing. These factors include appropriate forest management and methods to increase carbon sequestration, improve the efficiency of manufacturing processes, reduce waste and potentially toxic materials, and sustain healthy forest ecosystems. The intent is to create:

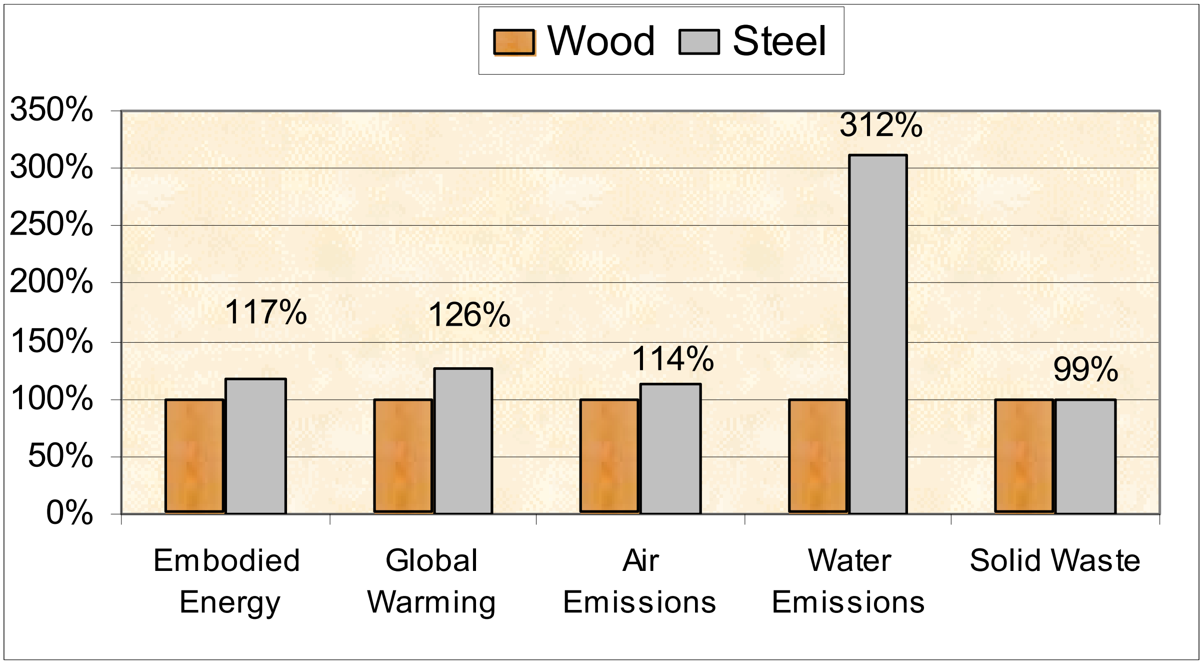
- A consistent database to evaluate the environmental performance of wood and alternative materials from resource regeneration or extraction to end use and disposal, i.e., from "cradle to grave.
- A framework for evaluating life-cycle environmental and economic impacts.
- Resource data for many users, including resource managers, manufacturers, architects, engineers, environmental protection and energy analysts, and policy specialists.
- An organizational framework to obtain the best science and peer review.

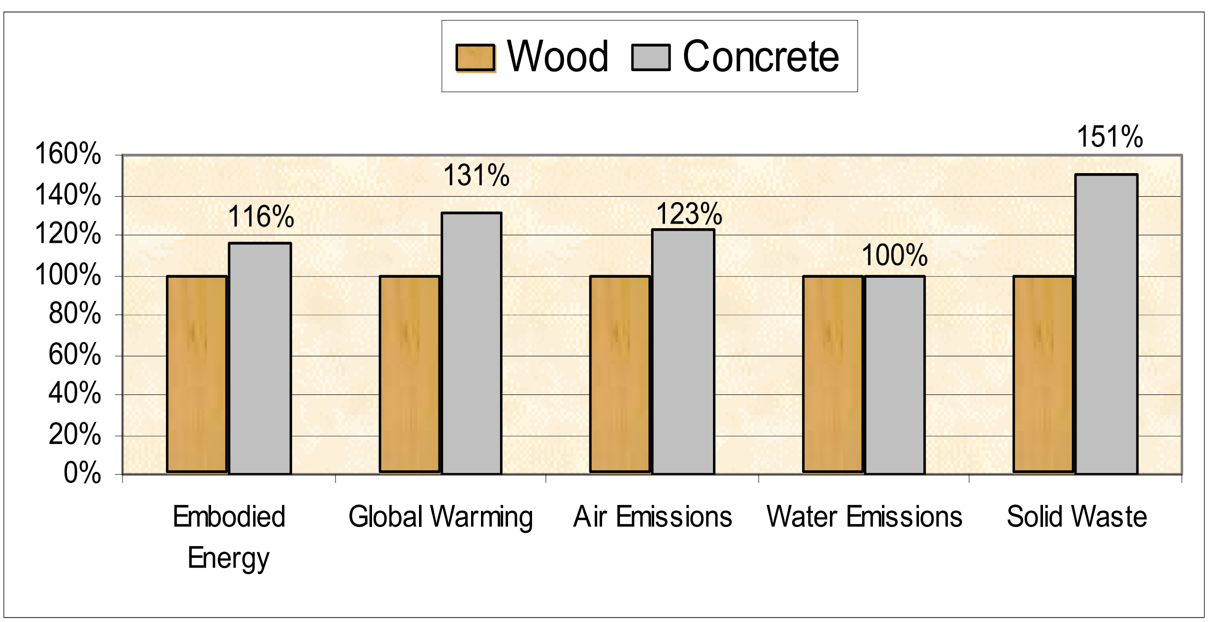
CORRIM's research is focused on two objectives: 1) to develop a database and modeling system for environmental performance measurements associated with materials use and, 2) to respond to specific questions and issues related to environmental performance and the cost effectiveness of alternative management and technology strategies.

CORRIM developed extremely detailed analyses of the embodied energy of two material options in two climate zones for a typical residential structure. The results show that wood-frame buildings have far less impact on the environment than alternatives as shown by the following examples.

The problem is that whenever the wood industry presents this data, the steel and concrete interests challenge it as using data biased to wood since CORRIM is a group of wood academicians even though they do their best to stay independent of the wood industry.

Wood to Steel Framed House Comparison in Minneapolis





Conclusions

So, the challenge is "what can the wood research community do to help better position wood as a green building material". Does this group try to support the CORRIM efforts as they generate new data? Does this group take a more active role in the tech transfer arena by better educating the students as they go through school? Does this group work with others in the wood products industry to come up with better communications tools focused on educating the practicing design professionals on what is really green?

There are a number of myths about green building materials typically favoring steel and concrete and discrediting wood. Can the wood research community become myth busters? The green building movement could be the best thing ever for the wood products industry in North America or it could be our worst nightmare.

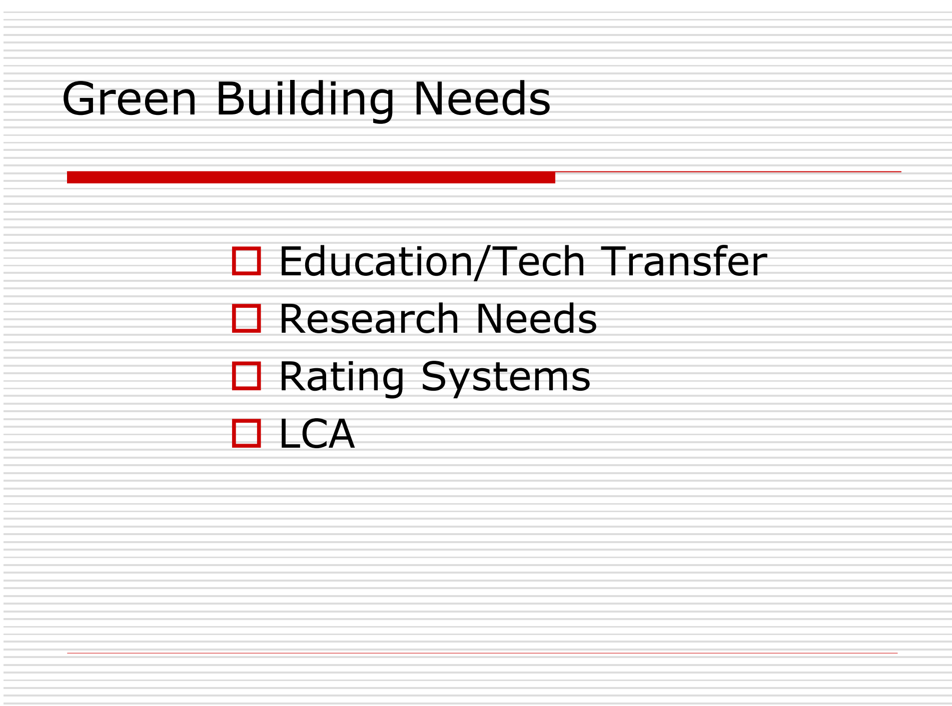
Session Summary

Summary Report of Discussion Groups #1, 9 & 17 on Green Buildings

Presented by

Tom Williamson (Moderator)

Ben Herzog (Scribe)



Education/Tech Transfer

- Audiences and their roles
  - Architects: Material type typically chosen at this level
  - Developers: Influence material choice
  - Engineers: Must be proficient in wood design
  - Students: Next generation of specifiers
  - Policy Makers: State of California (example)
  - Code Officials: Educational opportunity will occur if/when "green" is codified

Education/Tech Transfer

- Role of Academics
- Industry sponsorship of symposiums
- Industry sponsorship of student research
- Industry guest speakers/Industry teaching aids
- Sponsorship of design competitions/awards
  - Interdisciplinary
  - Solar decathlon model
  - Net zero energy / Carbon neutral building

Research Needs

- Product
  - X-lam (concrete substitute)
  - Bio-adhesives (zero formaldehyde)
  - "Green" coatings, stains, etc.
  - Treated wood using "green" chemistry
  - New engineered wood products using small diameter trees from thinnings
  - Converting "waste" into value-added products
  - Alternative fillers/core for SIPs

Research Needs (Cont.)

- Systems
  - Hybrid building systems
    - Advanced fasteners for hybrid systems
  - Fastening systems for deconstruction/reconstruction
  - Recycling/Recovering wood products
  - Hygrothermal Performance
    - Wall systems
    - Building science
  - Treated wood: disposal issues
  - Design with energy in mind
    - Solar
    - Light
    - Ventilation

Green Building Rating Systems

- LEED
  - Support LEED to accomplish changes from within
  - Shift emphasis from material type → research innovative systems to help wood structures gain points in other LEED criteria
- Green Globes: encourage credits for wood as carbon neutral (or better) and LCA assesement
- Product labeling
  - Formaldehyde emission
  - Carbon neutral
  - Potential to reduce global warming
  - Renewability / sustainability

Life Cycle Analysis

- *Standard method* needs to developed to incorporate LCI data from various sources.
- Cradle-to-grave analysis (?)
- Immediate need → focus on carbon footprint (learn from Europeans)
  - Use same procedure to compare all materials
- Make wood "greener" by recognizing minimal environmental footprint

Challenges

- Finances to accomplish educational objectives
- Change perception of Green = LEED = FSC
- Change perception of biased data
- Successful marketing campaign
- Focus industry efforts on competing with other materials versus competing with other wood materials

Summary Paper

Wood Engineering Challenges in the New Millennium: Critical Research Needs

GREEN BUILDING

Tom Williamson, Fellow, ASCE
APA – The Engineered Wood Association

While the wood industry understands that wood is a green building material, this is not the perception of most non-wood industry people, especially design professionals. The wood community has spent considerable effort trying to educate the greater population on the environmental attributes of wood. The *facts*, however, are oftentimes viewed as wood industry *claims,* due, in part, to persuasive arguments made by other interests (e.g., steel and concrete lobbyists). The question remains: how to convince design professionals that wood is not only a green building material but the *greenest* building material?

The following paper provides a summary of the discussions held at the April 2008 pre-Structures Congress workshop in Vancouver, B.C.

Education and Technology Transfer

Education and tech transfer are paramount to changing the way design professionals, and others, think about wood. Target audiences include:

- Architects – since material type is typically chosen at this level, architects are arguably the most important audience for education/tech transfer efforts.
- Developers – also influence material choice.
- Engineers – must be proficient in wood design; if not, increased education efforts on wood as a green material may be wasted.
- Students – represent the next generation of specifiers.
- Policy makers – state-mandated green certification programs are on the horizon. The State of California, for example, has recently adopted its own State Green Building Standard.
- Code officials: If/when green building becomes codified, it is assumed there will be a large demand for education from all of the groups listed above.

A good deal of discussion centered on the importance of education at the University level. Several academics present in the breakout discussions urged the wood industry to sponsor symposiums, student research, guest speakers, and teaching aids. In addition, it was suggested the industry sponsor a wood design competition. Such a competition could focus on the design of a net zero energy/carbon neutral building. A competition such as this could use the solar decathlon as a model, and should be interdisciplinary in nature.

Research Needs

It was concluded that increased research focused on (a) new product development, and (b) new building systems may also help wood products become, or at least appear, "greener". The following products were thought by the discussion groups to be deserving of increased R&D or investigation.

- Cross-laminated glulam, a.k.a. X-lam, as a concrete wall substitute
- Bio-based adhesives with the target of zero formaldehyde content

- "Green" coatings, stains, etc.
- Preservative treatments using green chemistry
- Engineered wood products using small diameter trees from thinning
- Alternative fillers/core for SIPs

"System-based" research needs include:
- A focus on hybrid building systems, whereby wood is used in conjunction with other types of building materials. In order to be effective, research on advanced fastening systems for hybrid building systems may be required.
- Development of fastening systems with deconstruction/reconstruction projects as the focus.
- Development on the appropriate grading systems and manufacturing processes required for producing engineered wood products utilizing recycled/recovered wood or wood products.
- Increased emphasis on building science, specifically, the hygrothermal performance of wall systems.
- Safer, cleaner, and greener methods of treated wood disposal.
- Increased emphasis on design with a focus on energy, e.g., solar, day-lighting, ventilation. It may be important to note that energy is the largest category in both the LEED™ and the Green Globes commercial building green rating system point allocation schemes.

Rating Systems

The USGBC LEED™ green building rating system has clearly become the dominant rating system in the U.S. To date, the wood industry has been critical of the LEED™ system due to fact that it discriminates against the use of wood products. As part of the discussion, it was noted that the wood industry needs to continue to support LEED™, rather than being seen as an adversarial group in order to accomplish changes from within. Perhaps simultaneously, design professionals should be encouraged to shift their emphasis from material type (as a means of scoring LEED™ points), and instead focus on innovative systems to help wood structures gain points in other LEED™ criteria such as indoor air quality and energy.

While working with the USGBC, the wood industry should also be promoting the advantages of alternative "wood-friendly" rating systems, such as the aforementioned Green Globes or the NAHB residential construction system, and encouraging these organizations to recognize, and grant credit for, carbon neutral or better products.

Another topic of discussion was introducing environmentally friendly product labeling to wood products. The labels could advertise the low or zero formaldehyde emissions typical of structural wood products, the fact that wood is carbon neutral, or the "renewability" aspect of wood products produced using wood harvested from managed and certified forests.

Life Cycle Assessment

One of the key tools for determining the impact of a building material on the environment is through life cycle assessment (LCA) often referred to as a "cradle to grave" assessment. But many criticisms of LCA stem from a lack of understanding the science associated with it, and questions regarding the materials data base that is used to measure, or determine, the life cycle inventory or LCI. In addition, the results of an LCA can differ drastically depending upon the life cycle assessment tools used. Therefore it will be extremely important to develop a *standard method* for LCA. This method should be able to incorporate LCI data from various sources in order to provide for a comparison of building products.

There are six specific measures often referenced in LCA for which quantitative information is specifically available for wood-based products: embodied primary energy, global warming potential, air emission index, water emission index, solid waste, and resource index. The development of a standard LCA method will be time-consuming and may be considered a "long-term" goal. In the interim, an immediate need is perhaps to focus on one of the LCA measures. It was suggested in the breakout sessions that the wood industry needs to focus on procedures for deriving the "carbon footprint" of wood products. As with the LCA, this procedure should be standardized so that a comparison of all building materials can be done. In doing this analysis it is important the chain of custody, on a system-scale, be considered. One participant urged the wood industry to follow the example of the European wood industry, in particular the European Panel Federation, regarding the marketing of woods small carbon footprint.

Challenges

The challenges facing the wood community are numerous. The industry needs to change the public perception that Green = LEED™ = FSC-certified wood. In addition, the wood community needs to change the perception that certain data, such as CORRIM's research, is biased. Accomplishing educational objectives, developing a successful marketing campaign, working on standardizing an LCA procedure, etc., will all take considerable time and money. Where will these resources come from? Finally, will the industry be able to come together to focus on competing with other materials rather than competing amongst itself?

Today's emphasis on green building could be a great opportunity for the wood industry, but to take advantage of this opportunity the wood products industry must (a) push for a common sense, scientifically-based approach to green building, (b) work to apply practical green measures in product manufacture, design, and building maintenance, and (c) continue to educate students, designers and builders on the benefits of wood as a green material.

HAZARD MITIGATION

POSITION PAPER

Natural Hazards and Wood Construction: The Road to Building Performance[1]

Dr. John W. van de Lindt, M. ASCE
Colorado State University
jwv@engr.colostate.edu

Abstract

Significant damage has resulted to light-frame wood buildings as a result of natural disasters.. Force-based design codes were intended to provide "life-safety" to occupants, during the design event, but do not explicitly address damage and the resulting financial losses which can occur during earthquakes, hurricanes, or flooding. Focusing on research experience over the last decade with performance-based design development, the author presents his position on what must happen if performance-based design (PBD) is to become a reality in the wood design community. Perhaps this can be thought of as "the road to performance-based design for wood structures". Development and implementation of PBD will result in better building performance during earthquakes, hurricanes, and even flooding. However, several major roadblocks exist, but the author encourages the wood research and design community to think of these as positives since the result is that PBD for wood will be customized for the wood design community and not simply borrowed from others. This will give the wood design community a challenge to address many of the key issues in structural (and potentially non-structural) performance that are not necessarily relevant in steel and concrete commercial buildings, and truly make PBD for wood a next generation design philosophy.

Introduction

Wood structures have performed relatively well during earthquakes and regular winds from the standpoint of life safety. Even in hurricanes, roofing systems designed to current force-based design codes do relatively well if life safety is the focus. Decades of research by numerous researchers worldwide at universities and at laboratories such as the Forest Products Lab (FPL) and Forintek Corporation (now FPInnovations) (e.g. Rainer and Karacabeyli, 1999) have resulted in standards and specifications which, in turn, produce designs with what society has deemed acceptable risk. The challenge is that society has based this acceptability on risk to fatalities and not the risk of damage or financial loss or ruin.

As a result of recent events a new design paradigm is developing, with major efforts being put forth in earthquake and fire engineering. In 1997, at the previous Research Needs in Wood Engineering Workshop, the idea of basing performance-based design on relative levels of risk for light-frame wood structures was put forth by Douglas (1997). This idea was very sound, but little has happened since that time to wood design codes that allow them to explicitly address building performance with the exception of several seismic proposals. In fact, if one looks at the

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[1] *This position paper is part of the Wood Engineering "Challenges in the New Millenium – Critical Research Needs" being held in conjunction with the 2008 Structures Congress in Vancouver, B.C., Canada.*

light-frame wood performance reports from hurricane Camille in 1969 and hurricane Katrina in 2005, the same sentences appear and the same problems persist. Performance-based design has the potential to change this for wood and allow engineers/designers to explicitly consider building performance during the design process.

In this paper, the author argues that if the tools can be put into place for three key elements, then PBD can become a reality. However, two major roadblocks (perhaps more) exist with regards to light-frame wood construction. It is up to the wood research and design community to face these head on and turn them into positives. This paper presents the authors roadmap or blue print on how this can be accomplished.

Mother Nature Speaks – Engineers Listen

Hurricane seasons over the last 20 years, particularly Andrew in 1992, the 2004 hurricane season, and Katrina in 2005 produced financial losses that were felt by the vast majority to be unacceptable. Following Andrew in 1992, stricter product and building regulations were developed and enforced in Florida. Then, following hurricane Katrina in 2005, several states adopted model building codes, e.g. IBC/IRC in Mississippi, as a result of what was felt by many to be an unacceptable amount of wind damage for the estimated wind speeds.

The 1994 Northridge and 1995 Kobe earthquakes resulted in a tremendous amount of damage to light-frame wood buildings in the U.S. and traditional post-and-beam construction in Japan, respectively. In fact, damage to wood buildings as a result of Northridge was estimated at between $16B and $20B (1994 US$). Both earthquakes were followed by large federally funded research projects from their respective governments: The CUREE-Caltech Woodframe project in the U.S. and the Dai-Dai-Toku project in Japan. The general goal of both projects for their respective construction types was to identify and characterize deficiencies, and to identify, investigate, and recommend categorical improvements and retrofit.

Not until the images of water covering New Orleans were nationally televised was the magnitude of flooding hazards taken to heart by the general public. In fact, in the U.S. 75% of declared Federal disasters are the result of flooding, and average an estimated US$2.4B in losses annually (not including 2005). Flooding hazard is not necessarily a structural issue but a product and land use planning and policy issue. However, as will become clearer throughout this paper, PBD does not address only structural details, but non-structural components as well.

PBE for fire is motivated primarily by economics and has been well developed. (Eillingwood et al, 2006). The Society of Fire Protection Engineers (SFPE) and National Fire Protection Association (NFPA) have developed an engineering guide to performance-based fire protection analysis and design of buildings, which outlines a process for using a performance-based approach in the design and assessment of building fire safety (SFPE, 2005).

Natural hazards tragically result in the loss of lives and combine to produce billions of dollars in damage each year. Other natural hazards, which are not explicitly discussed in this position paper but should also must be addressed are fire, wave/surge, snow, and durability issues. Many of these are linked, particularly with durability. Because this is a position paper, the author has opted not to use specific references since there are hundreds. However, for specific references the readers are encouraged to read van de Lindt et al (2008). Additionally several appear when a table or figure was excerpted from a previous document.

The Road to Performance

In order for structures to perform better during earthquakes, wind, and flood the wood design community must embrace new design concepts such as performance-based design (PBD). PBD is a design philosophy, or paradigm to be more general, that allows the stakeholders (e.g. the owner) the opportunity to identify what level of risk (or conversely, protection) they consider acceptable for a particular hazard. The design method itself is not explicitly formulated – only the hazard intensity level and performance expectation, either probabilistically or deterministically, are stated (Ellingwood, 1998). PBD has been embraced by other communities for seismic design, but not yet by wood. Interestingly, PBD has its roots in Housing and Urban Development's (HUD) Operation Breakthrough (NBSIR, 1977) of the 1970's whose objective was to fuel product innovation in the homebuilding industry by allowing designer flexibility and opportunities for better performance of components and assemblies within a building.

Successful development of PBD for wood has several major roadblocks to development and particularly implementation:

Roadblock 1: A fork in the road

As the name implies, performance-based design in its currently articulated form requires design. The vast majority of wood construction (i.e. light-frame wood residential) is conventional or prescriptive construction, not requiring engineering calculations. Thus, a fork in the road with one prong being engineered construction and another being prescriptive construction, is present. Because of this challenge, and the fork in the road which is not present for other building materials, it can be inferred that PBD for wood may not take the same form as it has for other building materials used in construction. It is certainly easier to envision performance-based design for engineered wood construction such as light commercial buildings, than for single family dwellings. This must be considered as a positive ultimately, but means basic development for the wood research community rather than simply borrowing methods.

Roadblock 2: Construction Quality

For many non-engineered wood buildings the quality of construction is not guaranteed. Although this is not a design code issue, it will be difficult to determine if deficient performance during extreme natural hazard loading events is the result of the PBD code or construction issues left unaddressed. At the very least the issue of accounting for the variability in performance introduced by construction quality variations resulting from site built construction, and the use of trades people with varying levels of expertise.

Three key elements within the wood engineering community must be put into place for PBD for earthquake, wind, and flood to be eventually realized:

Table 1: Performance Expectations and Descriptors (Ex in part, van de Lindt et al, 2008)

	Performance Expectation				
	Occupant Comfort	**Continued Occupancy**	**Life Safety**	**Structural Integrity**	**Manageable Loss**
Hazard	**Little or no reduction in living/ inhabitant comfort**	**Up to moderate reduction in comfort but no threat to safety or injury. Electrical, plumbing, egress still present**	**Structural integrity is questionable; significant risk of serious injury; safety normally provided not present**	**Structure is visibly unsafe**	**Expected or risk of total or annualized loss has been discussed and is understood by owner and stakeholders**
Seismic	1% Inter-story Drift (ID)	2% ID	3-4% ID	7% ID	ABV[2] Loss Fragilities
Wind	No water entry 1/8" uplift on panel edges	Breach of windows or doors. Loss of a portion or full gable or sheathing panel. Strength exceeded analysis	Roof truss-to-wall connection failure. Supporting column/post failure. Strength exceedance analysis	Collapse of roof; loss of lateral capacity. Strength based analysis	Cost of repair less than some % of replacement value. % is less without insurance
Flood	Not Applicable	Water recessive by pumping or natural means possible. Ventilation possible/mold abatement. No sewage backup, no structural damage, no water entry to mech and elect	No structural damage. Flooding may prevent egress. Flooding depth is significantly high.	Visible damage to structure	Cost of repair less than some % of replacement cost. Dependent on insurance.

[2] ABV = assembly-based vulnerability

Key Element 1: Performance Expectations

Performance expectations must be agreed upon. These can vary significantly depending on the desired level of protection the owner would like for his/her building. Even more importantly some kind of performance descriptors, which correlate closely with the various performance expectations, need to be developed and agreed upon. Table 1 shows some example performance expectations with example performance descriptors for earthquake, wind, and flood. Performance expectations have been discussed within the context of seismic PBD for years. At a recent PBD of woodframe structures workshop (van de Lindt, 2005) held in Fort Collins, CO, five expectations were developed. Those shown in Table 1 were further developed after the workshop for earthquake, wind, and flood and represent an attempt to define some example performance descriptors.

Ultimately, these correlations between damage descriptors and performance expectations should be rigorously developed through testing.

Key Element 2: Numerical Model Improvement

Current component and assembly models such as connector, shear wall, and truss models, are reasonably accurate for wood structures subjected to seismic and wind loading. As the components and sub-assemblies are integrated into larger and larger system level models the accuracy decreases. Table 2 presents an estimate of the current "grades" assigned by the author based on experience with all three types of system level models with the justification for these grades provided below.

Table 2: Grades for Numerical Models being used in early stages of PBD of Wood

Hazard	Model Type	Grade
Earthquake	Nonlinear time history with rigid horizontal diaphragm assumptions (3 DOF or 6 DOF per story)	B
Wind	System pressure/uplift model capable of identifying component/assembly failure based on nail level	B
Flood	System model capable of predicting failure of components due to water/moisture	C

Earthquake modeling of wood buildings has improved dramatically over the last decade. Several studies have entertained the possibility of a full 3-D finite element model with every nonlinear fastener included. Even with today's computational speed this type of analysis is only justifiable for research and may even be difficult to justify in that regard. Models have recently been developed that model each shear wall as a nonlinear hysteretic spring element and have had good success. Models have also been extended to include uplift springs to capture rocking and sill plate uplift, continuous hold down rod systems, and non-structural elements such as gypsum wall board (GWB) (drywall) and exterior siding or stucco. The major roadblock for numerical modeling of wood buildings is the inability to capture the interaction of the various construction layers. Thus, the use of a reasonably complex model brings into question the ability to predict the response, but more importantly the performance and subsequently the damage state, of light-frame wood buildings. However, the numerical models for load which consist of 2-D or 3-D earthquake ground acceleration input are based directly on recorded ground kinematics and are quite accurate, so if the objective of these models is to predict the performance of light-frame wood buildings, then a grade of "B" seems appropriate, until some of these modeling details are worked out.

Modeling wind flow around a building is extremely complex with localized effects substantial. For light-frame wood residential buildings the floor plans and roof geometries (e.g. various combinations of hip and gable) are becoming more complex as society demands less "box like" homes. Wind charts such as those in ASCE 7 (2005) provide wind speeds which are converted to pressures depending on structural geometry and site characteristics. As with modeling of a structure to earthquake load there is the accuracy of the loading and the accuracy of the load/response model to consider.

One of the most common problems associated with high winds is loss of roof coverings and sheathing. In the past, sheathing panels have been tested as sub-assemblies using air pressure on the under-side of the panel to determine the overall panel capacity in e.g. psf. While these type of tests are valuable they ultimately should serve only to confirm mechanistic models such as the type being "graded" here for discussion. Modeling roof systems to wind uplift is beginning to get closer to experimental results with detailed nail models in a panel finite element mesh capable of reproducing panel results within 10% of the mean value of the panel for ten tests. The key is in accurately representing and modeling the variability in the materials, e.g. nail type, OSB or plywood MOE and MOR, and the specific gravity of the truss member since even over the range of each species or group this makes a difference. The problem arises in that the very purpose of these mechanistic models is so one doesn't have to perform experiments each time an analysis is sought. While this variability is inherent in all wood-based products it must be addressed sufficiently to allow these models to accurately integrate into PBD methods for wood. Because of this high level of variability which affects models and the errors with respect to localized wind effects due to complex structure geometry a grade of B is given to numerical wind models for light-frame wood.

System models for flood are virtually non-existent due to a dearth of time to failure data for many building (and other) materials. Several studies by trade organization, manufacturers, and university researchers have been conducted to identify when a building material failed or was non-repairable after coming into and maintaining contact with water. One problem with several of the studies is that the time to failure data was discretized between, for example, 3 and 6 days, further increasing the coarseness of the failure data. PBD for flood is further complicated in that it is not a strength or stiffness issue like seismic and wind, but rather a financial loss issue. Ultimately, seismic and wind are also financial loss issues but can be addressed through strength modeling concepts and performance descriptors that relate back to strength, e.g. nail pullout strength for roof sheathing or wall strength and stiffness for shear walls. Because of a severe lack of data (or lack of availability of data) for many components and assemblies that come into and/or remain in contact with water, a grade of C is given to the few models in existence.

Most importantly, each of these model types discussed and "graded" above must be able to produce accurate estimates of the performance descriptors that help determine if a particular performance expectation (Key Element 1) was achieved. If these models can be used with confidence and confirmed through rigorous experimental test programs, then all that will remain is the agreement of a format for PBD of wood, and subsequent refinement.

Key Element 3: Philosophy and/or Format

Unfortunately, this key element is not as easy as it first sounds. Recall, at the very core of PBD is the opportunity to leave the design approach to the engineer or engineering team and not prescribe a method. Juxtaposed to that is the typical light-frame wood design approach which does prescribe a method. Thus, one key element that must occur is the development of a different format for PBD of wood than is currently evolving for other types of buildings. It is likely that this will be somewhat prescriptive using tables, charts, or combinations thereof with the specified opportunity to directly utilize numerical models. Whatever the format for PBD of wood subjected to natural hazards loading, it is expected to provide designs whose level of safety exceeds that currently provided by designing to loads in ASCE 7-05 (2005).

For example, it has been discussed that one way to improve performance of light-frame wood buildings during hurricanes is to design the cladding and other (classically non-structural) details to a specific performance level. If these hold, the building envelope remains intact, and water penetration is unlikely. It is also likely that the light-frame wood community must embrace other materials in the form of mixed construction. The PBD philosophy must embrace mixed construction to become a viable design methodology.

Summary and Closure

Figure 1 presents a graphical summary of what the author feels should occur over the next half decade to allow the development of a pre-standard for PBD of wood. The 1st Invitational Workshop on Performance-Based Design of Wood was held in Fort Collins, CO in 2005 as part of an SEI Special Project. It is anticipated that the 2nd Workshop will be held in 2008 to refine performance expectations and help move performance-based design of wood forward and up the path in Figure 1 to a pre-standard for PBD of wood and eventually a standard. Although only earthquake, wind, and flood were discussed herein the issues for durability, snow, and, to some extent, fire are the same with various levels of performance expectation needing discussion and refinement by the wood research and practitioner community. Better numerical models for underlying research and design, and a format selected that is specific (at least partially) to PBD of wood are critical if PBD for wood structures is to be developed.

Acknowledgements

Thank you to the steering committee for the research needs workshop for their helpful comments during the preparation of this paper. A special thanks to David Rosowsky and Erol Karacabeyli for specific written comments and discussion.

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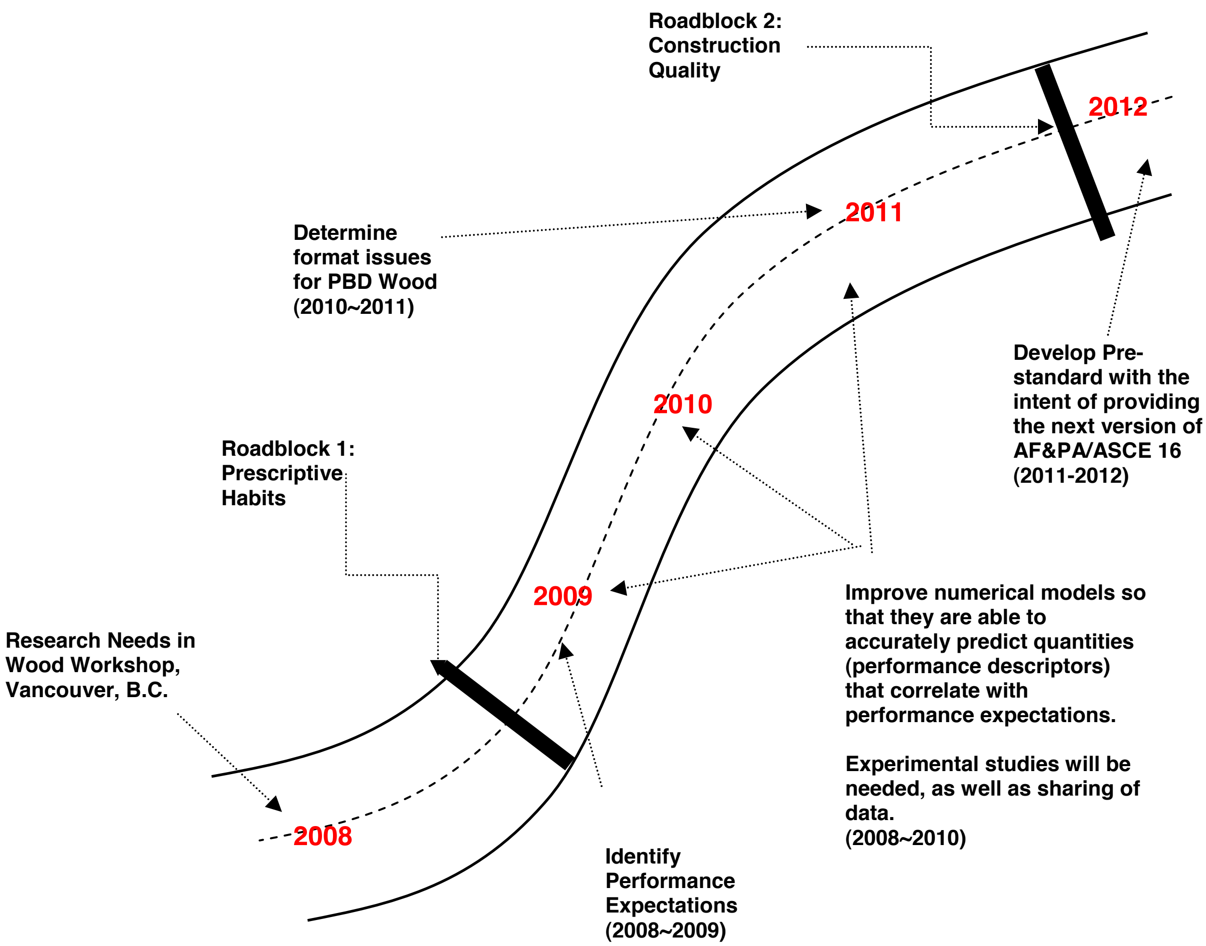


Figure 1: A conceptual summary of the proposed road to PBD for wood

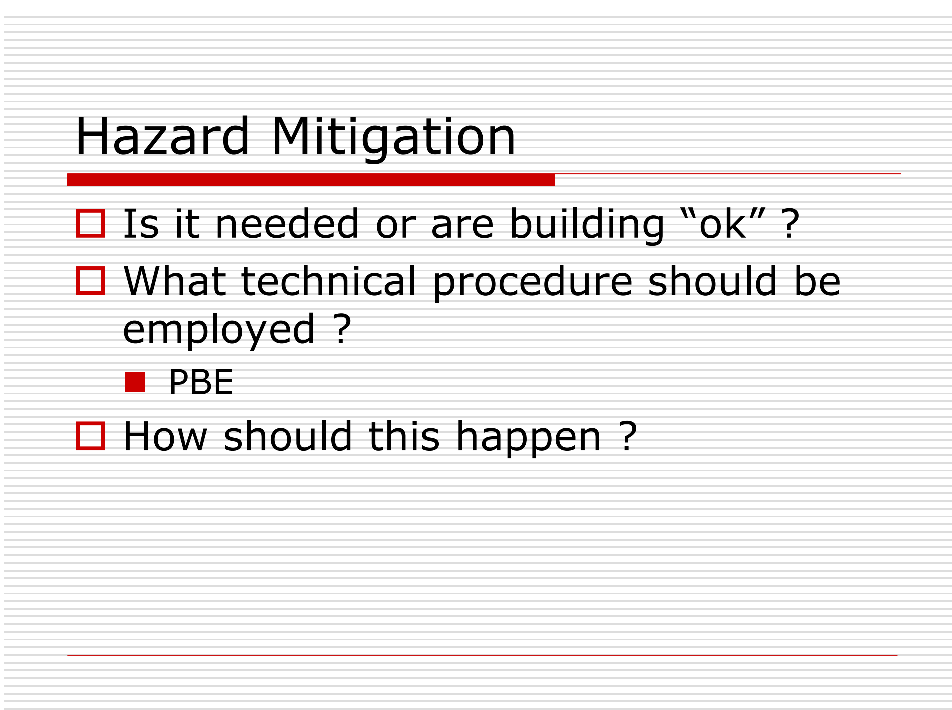
Session Summary

Summary Report of Discussion Groups #2, 10 & 18 on Hazard Mitigation

Presented by

John W. van de Lindt (Facilitator)

Shiling Pei (Scribe)



Performance-Based Engineering

- What is it ?
  - Explicitly consider performance under specified hazard conditions
  - Multiple criteria at multiple hazards
- We can build better, why don't we ?
  - Too difficult, too involved
  - Cost too much to engineer, to build
- Motivation
  - Government wants people at home following event
  - Sell with independent rating system
  - Multihazard mitigation council - $1 → $4
  - Insurance breaks not possible yet
- Ideally PBE must be in terms of losses
- Residential and light commercial might differ

Cost

- Life cycle costs must be considered
- Just dollars not enough, societal implications or impact
- Some common metric for decision making

How do we get there ?

- Need to "sell it"! To whom?
  - All stakeholders – owners, government
- Education/knowledge level
- Rating system by independent body (e.g. similar to LEED)
- Careful of perception
  - Socio-economic, political
- Enforcement for rating
- Demonstration project
  - Builders on board

Modeling

- Felt to be critical by all groups
- Need better models
  - e.g. non-structural components
- User friendly if engineers are to use
- Ability tie to loss analysis
- Benchmark procedure to evaluate models
  - Some existing data
  - May need some verification tests (systematic)
  - Load models for hazards are poor
  - Contents damage modeling for loss

Linking Drivers

- Life and Property Protection
  - Hazard mitigation, in general
  - PBE – even better
- Sustainability and Infrastructure Renewal
  - Resilient structures use less resources over time
  - Improves housing/building stock

Thank you to all the break out participants and for your attention!

John W. van de Lindt
jwv@engr.colostate.edu

Summary Paper

Summary for Hazard Mitigation Breakout Group

ASCE PRE-CONGRESS WORKSHOP

Wood Engineering Challenges in the New Millennium – Critical Research Needs

Prepared by: Facilitator Prof John W. van de Lindt, ***Colorado State University***

Scribe: Dr Shiling Pei, ***Colorado State University***

Hazard Mitigation and Performance-Based Engineering

In general, each of the groups began by questioning whether there was a need for change, i.e. was current construction "o.k."? If it was not, then what technical procedure should be implemented and how should it happen? As facilitator I suggested performance-based engineering (PBE) which was also the subject of my position paper prior to the workshop. This involves an articulated, and raised, level of performance and may include multiple criteria. Several groups stated that society can build better and more resilient homes, but why don't we? The answer always came back to cost. Either it was felt to be too difficult, too involved, or simply too costly for a SFD. The discussion turned to the motivation for considering implementation of such a methodology which were (1) the government wants people at home following a natural hazards event with shelter intact; (2) it might be possible to sell these "upgrades" but they would need some type of independent rating system; (3) the multi-hazard mitigation council concluded that for each dollar spent on hazard mitigation, four dollars are saved; The only negative was that insurance breaks are not available yet, but this is changing in Florida. It was agreed that PBE should ultimately be calibrated or developed in terms of losses, and that the approach for residential and light commercial might differ.

Cost and "Getting There"

It is important to include life cycle costs which would have a significant impact on motivation for government and insurance groups. Dollars alone are not enough – societal implications must be included in the calibration and/or development to have any reasonable probability of implementation. Some common metric for decision-making is needed, whether it be loss or some other hybrid quantity. To fully develop and implement PBE, we need to decide who to sell it to? The answer is, of course, all stakeholders. We also need to provide education and knowledge on the subject either through workshops or some other mechanism. It is important to be sensitive to socio-economic perception, particularly if the PBE designed dwellings are perceived as being "safer" than force-base designed homes. In addition there would need to be some type of enforcement for rating and ultimately a demonstration project with a builder and a community or communities.

Modeling

Modeling in order to design was felt to be critical by all groups. In particular, it was agreed that models need improvement and that non-structural components contribute substantially but are not modeled accurately. The models must be user friendly if engineers are to use them and should be tied to the loss analysis, but without the engineers having to perform the loss analysis. There should be some type of benchmark procedure to evaluate the models, e.g. some existing data sets.

Linking to Drivers

Hazard mitigation links directly to "Life and Property Protection" and performance-based engineering provides even a stronger link as it improves upon protecting both life and property. PBE provides resilient structures that use less resources over time and improves the housing and building stock, thereby linking to "Sustainability and Infrastructure Renewal".

ADVANCED MATERIALS

POSITION PAPER

Advanced Materials

Michael P. Wolcott
Department of Civil and Environmental Engineering
Washington State University
Pullman, WA 99164-2910

Lech Muszński
Department of Wood Science & Engineering
Oregon State University
Corvallis, OR 97331

Abstract

Looking back at the past decade one may be surprised at the modest changes the wood-based composites industry has experienced during this time. Particularly when the state of the industry is compared with the dynamic growth period of previous decades and the tremendous changes in the environment, in which it finds itself at the end of the first decade of the 21st century. The nearly uninterrupted boom in the housing market between 2000 and 2006 provided more impetus for capital expansion of existing technologies rather than a strong stimulus for innovation. The primary progress that has been achieved is in the industry's efficiency and sustainability of processing. This is contrasted to the rapid advances in material types and innovations that was the signature of the previous two decades. Now we are manufacturing more of the same commodity products in a similar, though more efficient manner. Notable exceptions are the mainstreaming of the wood-plastic composites for exterior applications and the burgeoning call for bio-based and non-formaldehyde resins in the particleboard and fiberboard industries. However changing dynamics of the marketplace in the last few years has brought new challenges and opportunities to the wood-based composites industry.

The objective of this paper is to collect and communicate some of the perceived needs in structural wood materials research through the next decade. Being conceived prior to any formal planning process, this document is neither complete nor conclusive. Rather, it should be viewed as a point of reference and a place to begin discussions.

This paper begins with a brief review of the challenges and opportunities facing the wood-based composites industry and the research needs directly related to these challenges. In the second part of the paper a brief overview of the state-of-art in wood-based materials and components that are commercially produced and commonly used in construction is offered. The major challenges and research needs specific to these products are then organized in several broad categories that include: Materials Design and Production, Materials Performance, Materials and System Assessment, System Approach.

Challenges and opportunities

The challenges and opportunities confronting the wood-based composites industry may be summarized in the following categories: 1) globalization of wood-based composites; 2) increasing costs of energy and petroleum; 3) short and long term consequences of the collapse of the domestic housing market; 4) the global call for sustainability in industrial and construction practices; and 5) regulations regarding use and emissions of hazardous chemicals in wood products.

Globalization of the wood-based product market

Once the domain of consumer items, the globalization of the wood-based composites industry has had profound influence on the domestic industry. The rapidly changing landscape of the global economy and labor market has been aided by access to information and technology, as well as low costs for shipping. With these international forces, highly developed countries such as the US, can hardly maintain their competitive advantage in manufacturing low-cost commodities. To achieve and maintain the necessary competitive edge in the global economy requires companies to be innovative and technologically dynamic. (Archibugi, Howells et al. 1999).

It is clear that for the wood composites industries in the developed countries to maintain long-term growth they must assume a leading position in developing new, advanced materials and technologies. In addition, this new culture of innovation must be made a permanent self-sustaining process (Grossman and Helpman 1991). For North American producers, the pressure of the foreign competition has forced innovations that lead to significant improvements of the manufacturing processes, resulting in more streamlined productions that are more efficient than ever. The ideas of optimized organization of the process or lean manufacturing practices have been making their way through primary wood processing operations and it is expected that in the next decade they will affect the way wood-based composites are manufactured. However, these same forces of innovations must be exercised on the development of new materials and products similar to those seen in the emergence of wood-plastic composites.

Increasing costs of energy and petroleum

After a relatively stable energy market of the 1990s, the prices of gas and oil began to steadily increase in 2003 resulting in a cost rise of approximately 250%. This trend is more than likely to continue in the coming decade and will have tremendous impact on the wood-based composites industry. Although the majority of a wood composite is produced from renewable materials, the industry consumes great amounts of energy in the drying and hot pressing steps and relies on petroleum-based thermoset adhesives. The industry has responded to this pressure with innovations leading to greater energy and resin efficiency. Today, many facilities have become net producers on electrical energy or process steam by burning unrecyclable production wastes in co-generation facilities. However impressive this development may be, it is unlikely to solve the problem in the long run. In an effort to take another major step towards sustainability, recent research has begun to explore manufacturing processes that would reduce the massive energy input for drying and curing of composites (Harper et al. 2006; Du et al. 2005; Berejka and Eberle 2002; Guasti and Rosi 1997) The importance of this research will certainly continue in the coming decade and it is likely to bring a paradigm shift in the way wood-based composites are designed and manufactured.

Fueled by price volatility of petroleum derived fuels (Sherman et al 2004), as well as increased regulation on non-structural wood composites using urea-formaldehyde resins (Harbatkin 2007), the past decade has also brought a greater interest and need for bio-based adhesive for wood composites industry. New thermoset adhesives may have potential advantages over the phenolic resins: e.g. derived from renewable raw materials, provides improved durability and in the industrial production may be less expensive than the traditional resins. One soy-based adhesive is in the stage of industrial trials now. In the coming decade bio-based resins may significantly reduce the use of the formaldehyde-based resins in the wood-based composites industry.

Collapse of the domestic housing market

It is clear now, that the tremendous development of the housing market which provided so much steady demand for the wood-based structural products in the last five-years has been fueled by unsustainable banking practices. Virtual collapse in the housing market is an additional blow to the industry, which combines unfavorably with other challenges listed above. What these societal changes mean to the domestic commodity industry remains an open question. Does it: Close? Reinvent itself? Look beyond structural products? Look beyond the domestic market? Stress innovative specialty products over cheap commodities? Clearly an enormous challenge exists for research and collaboration between the industry and academia. One of the results was increased interest in research on advanced engineered wood and bio-based products.

Imperative of sustainability

Global concerns over the climate change and shrinking availability of many natural resources forced the global community, governments, industries and researchers to rethink the way the global resources are used. The concerns resulted in a requirement for more sustainable practices in utilizing natural resources, manufacturing, construction, distribution and consumption of goods.

In a sense the stress on sustainability gives a wider framework to many specific concerns and challenges discussed above. Just as the wood composites industry was borne from the environmental call of the 1960's that eliminated open burning of wood wastes, so too could this new focus on sustainability help to transform this industry. The immediate challenges for the wood-based composites industry are:

1. Changes to the raw material resource base
2. Increased pressure and regulations on waste and pollution management practices
3. Need for improved recycling of construction materials

The responses of the industry and the research community to the previously discussed challenges fit naturally in this wider framework. A unique response in the research community has been the emergence of life cycle analysis research/science as evidenced by renewed efforts by CORRIM

In 2007 alone, the US federal government spent nearly $2 billion to fight forest fires on federal lands (Daley 2008). Utilizing raw material resulting from wild fire prevention operations like forest thinnings and forest fuel removal is a research need that is likely to emerge. To be successful this effort will not only require engineering solutions but also collaboration between the industry, federal and state governmental agencies, and local communities and possibly state agencies. Use of this fiber in value added composite products is expected to create consistent demand for bio-particles, which might also offset high costs of the removal operations and improve the economics of controlled burns (Mason, Lippke et al. 2006). This effort speaks to much wider framework of the idea of sustainability. Significant gains would be realized in the overall carbon storage of the forest stand (Tilman et al 2000). Apart from improved fire safety, local communities could benefit from small and medium scale business opportunities generated around such production.

Regulations

Two important regulations, one implemented and one in the making, may have a tremendous impact on the wood-based composite industry and the research needs in the coming decade. These regulations are: (1) the federal ban on CCA in residential applications and (2) the regulations of the formaldehyde emission in composite wood products.

Federal ban on CCA in residential applications: In December 31, 2003 CCA, the common preservative treatment for consumer wood products, was banned from residential applications. Despite strong demand and a substantial research effort, to date, no equally effective substitute has been found. The quest for an effective and commercially feasible way of protecting wood from deterioration is certainly going to continue in the coming decade.

Formaldehyde regulations: "The California Air Resources Board established new regulations in April 2007 to regulate formaldehyde emissions from composite wood products, including particle board, MDF (medium density fiberboard), and interior plywood. The two step process set limits on emissions for products manufactured after January 1, 2009 that will be roughly equivalent to the majority of the European and Japanese standards and will exceed them with stricter limits in 2010 (and 2012 for some products). These standards will not eliminate the addition of formaldehyde during product manufacture, but will make formaldehyde free alternatives [like the new soy-based adhesive mentioned above] much more competitive." (http://www.healthybuilding.net/formaldehyde/index.html)

State-of-art in wood-based materials and components used in construction

Commercial composite materials and structural elements can be classified by their intended uses and constituent wood element that is used in production (Table 1). In wood construction, structural beam and plate elements are by far the most common. Some molded and extruded composites are currently available, however, these are used in non-structural applications like windows and door frames, interior automobile parts and furniture as well as in semi-structures like decking. Although early structural composites were produced from large wood elements, like lumber and veneer, in the past decades a strong influx of strand-based systems for both the beams and plates. This trend had been fostered by changes in resource and continues increasing the utilization of previously underused or unused raw material resources (alternative tree species and small size classes etc.).

Almost without exception, wood-based composites have been developed to directly replace other construction materials. The earliest trend was the large-scale substitution of plywood sheathing for board sheathing. In 1980s plywood lost significant segment of the sheeting markets to OSB. A decade later, the commercialization of I-joists successfully challenged large dimension lumber applications in floor and roof framing. A decade ago, engineered lumber products have hit the 2x4 market; the smallest common commercial lumber size. The newest developments are the combination of these composite elements in components that are engineered and code accredited to accomplish specific structural tasks. The earliest evidence of these pre-assembled components might be seen in the truss industry. The recent emergence of shear panels may be a sign that pre-engineered wood components might be the new generation of composite building components.

Table 1: Commercial wood-based composite materials ordered by use and constituent wood element.

COMMERCIAL WOOD COMPOSITES				
	Beam	*Structural Plate*	*Non-Structural Plate*	*Molded and Extruded*
Lumber	Glulam	Glulam	---	
Veneer	Laminated Veneer Lumber (LVL)	Plywood	Plywood	Sporting Goods
Strand	Composite Strand Lumber (CSL)	Oriented Strand Board (OSB)	---	Chair Seats
Particles	---	Particleboard	Particleboard	Pallets
Fiber	---	---	Hardboard, MDF, Insulation Board	Door Skins, Interior Auto Components
Components	I-Joists Trusses	Structural Insulated Panels (SIP)	---	---
WPCs				Decking, Railing, Windows and Door Frames

Wood-composites have produced dramatic increases in building efficiency. Light-weight combined with large sizes had both contributed to ease of application. The new products like finger-jointed and CSL wall framing lumber are aimed directly at use characteristics (i.e. straightness, consistency, etc.) that are declining from the decreasing quality of solid framing lumber. In the cases of beam elements, the improved engineering properties have changed building design primarily by increasing unsupported span lengths for roofs and floors. However, none of these materials have substantially changed the basic concept of light-frame construction. One exception to this rule is structural insulated panels (SIP's) which replace entire structural wall and floor systems. SIP's have seen their greatest success in the modern timber-frame market, as opposed to traditional light-framed buildings.

A promising trend of the 1990s was development of hybrid composites that combined wood with synthetic materials (Table 2). Although in the past decade significant advances were made in the science of these materials the commercialization of most of the hybrid composites is slow. A major driving force for this interest had been the increased competition by synthetic materials in the traditional arena of residential construction. The major impetus for hybrid composites was the need to produce a material that combines the availability, lightness, machineability, and mechanical properties of wood with durability and environmental resistance of synthetic materials. These needs were most evident in durable materials that are resistant to moisture and bio-degradation. The one exception had been reinforced glulam technology, which aimed primarily at the long span markets captured by LVL and CSL. In previous decades, with raw materials for the traditional wood-based composites being easily available and relatively inexpensive the most significant barrier for these materials was cost. Hopes for greater competitiveness of these materials with increasing prices of fiber, customer acceptance and code mandates were offset by rapidly increasing prices of energy and petroleum a major raw material for many synthetics. It is also true that the promises of superior environmental durability of these materials proved to be very optimistic.

Table 2: Commercial hybrid composites that combine wood with synthetic materials.

COMMERCIAL HYBRID COMPOSITES	
Technology	*Application*
Synthetic Reinforcement	Glulam
Inorganic Bonded	Siding
	Roofing
	Wallboard
	Underlayment
	Tile-baker
Polymer Impregnation	Flooring

Materials Design and Production

We believe that the resource-based issues will proceed to drive many of the research needs in design and production of wood-based composites, as they had been in the past decade. This trend will continue primarily from the increased percentage of small and under-utilized forest resources in the available cutting stock. As mentioned in the first section of the paper, significant effort has been made to research ways of utilizing and recycling in value added products raw material generated by refining of residues from forest products manufacturing, processing of small diameter trees, undergrowth and other wood residues resulting from forest thinning programs and forest fuel.

Interest in recycling post-consumer wood waste increased during the 1990's from a decreased availability of sawmill residues in the western US and an increased consumer interest in recycled materials nationwide. Past decade has seen significant industry wide effort to utilize this new resource. Virtually all particleboard and MDF mills now incorporate a significant share of postconsumer waste as well as waste from other wood-based composite manufacturing operations in their raw material supply. Significant effort has been made on part of the industry to offset or moderate the impact of the recycled supply quality on the quality of the product.

The use of recycled material in structural applications remains in the early development stages. Recycled timbers are currently in large demand for niche markets like timber framing. However, appropriate grading technologies and standards are needed for reuse and remanufacture of solid wood components on a large scale. Among the largest challenges of recycling for building materials is the poor ability to separate materials during demolition. The concepts embodied in "Design for Deconstruction" (Pulaski et al 2003) may be the largest challenges and greatest contributions for sustainability of wood building materials.

An increased emphasis on hybrid composite technologies will be needed to expand the performance envelope of wood-based materials. The volume of residential housing markets is enormous compared to those currently realized by most synthetic materials, especially reinforcing fibers. An increased use of synthetics in combination of wood-based materials should drive cost improvements for these components. Many of these products – notably WPCs – are perceived as precursors of new generation of wood-based materials, which speak to the ubiquitous imperative of sustainability. Even now, the hybrid composites have the potential of phasing out many materials of heavier carbon foot print in areas of limited structural responsibility. In particular, the possibility exists to replace up to 70% of petroleum-based polymers in products currently manufactured entirely from plastics. They also respond to the need of recycling and utilization of the lowest grade raw materials.

However, increased use will only come with improved economics and performance of the hybrid materials. Research efforts should strive for more efficient use of the synthetic components, improving the mechanical and environmental performance of these composites as well as on finding bio-based alternatives for the thermoplastic polymers used as matrix/binder. Technologies that improve resistance to moisture and bio-degradation with reduced dependence on biocides are particularly important. In addition, novel processing methods will assist in both economics and roles for synthetics. Other important stimuli are rapidly growing prices of energy and raw petroleum, which drive costs of processes, which require significant energy inputs and quantities of synthetic adhesives.

It is also envisioned that recent progress and accessibility of integrated experimental methods and modeling will significantly aid the process of improving the existing composites and designing and virtual prototyping of new ones. Achieving this goal requires coordinated multidisciplinary research effort that is aimed at producing fundamental knowledge in shared databases to facilitate rapid adoption of these methods.

A final area for potential development in hybrid composites is the new generation of nano-materials. Although, currently these materials seem to have a long way towards the commercial scales necessary for building materials, the potential for major breakthroughs in material performance and transformational technologies are great.

Materials Performance

Many of the concerns or deficiencies in wood-composite performance can be categorized as durability issues. Specifically, durability can be viewed as (1) creep and duration of load (DOL) performance, (2) moisture absorption and the resulting degradation in material properties, and (3) biological degradation.

Creep performance of many non-veneered wood composites has been shown to be extremely poor in laboratory studies. However, these results contrast strikingly to the absence of actual creep related failures in the field. Research is needed to address the actual load histories of materials and representative testing regimes. In addition, it is critical to develop accelerated test methods that produce meaningful data for both engineering analysis and product performance.

Composite materials abound for a variety of interior applications, however, many of these materials are difficult to treat for exterior use. The common preservative treatment for consumer wood products is CCA which actually decreases the moisture related weathering performance of wood has been banned from residential applications since 2003. There is a great need to expand the research on alternative treatments or product performance towards moisture and decay durable wood composites.

As wood engineers, we often concentrate attention on the structural components of a building. However, non-structural materials that are used in doors, windows, siding, trim, and roofing often comprise the largest cost of a residential structure. These materials are foremost in the minds of the owner since it is these materials that they contact daily. In addition, these non-structural components often have strong influence on the reliability and longevity of the structure they protect. The court records stand testimony to our need to continue research towards durable and reliable wood-based composite products for these exterior applications.

Wood has flourished over the years as a construction material primarily from its ease of use and widespread availability. These attributes combined with the new perception of wood as a renewable and sustainable material have continued to drive much of the success for engineered wood composites like LVL and CSL, which can be higher cost than standard steel sections in many applications. The continued quality decline of solid wood framing materials is an ongoing challenge to direct research needs towards property requirements of CSL framing material.

Materials and System Assessment

Non-destructive evaluation (NDE) techniques are currently well established within the wood lumber and composite industries. Many of these systems have a high cost which are then passed onto the material cost. As such, the use of MSR lumber is fairly restrained to pre-engineered materials. Research is needed for low-cost NDE that can be widely used for both composites and solid wood. These techniques should be flexible enough to accommodate in-place evaluation of materials. In contrast to the classical deflection techniques that are often used for lumber evaluation, stress-wave timing and ultrasonics have this flexible capability. Similar systems can provide data that can be used in property assignment and load assessment with similar methodologies.

Many problems associated with wood-based materials in construction can be traced to problems with construction practices. Currently, these practices are difficult to inspect since many of the materials are covered at key inspection times. In addition, current inspection standards are qualitative in nature. NDE techniques that can assess the general integrity of building systems would provide invaluable information influencing perceived material performance.

System Approach

Current wood-based materials have been designed as a direct substitute for solid lumber products. Opportunity now exists to coordinate material and structural system design to optimize performance. Connector behavior with composites is an often over-looked area for wood-based materials. Here, design can be focused on both novel connections and composites that optimized for traditional connections. A combined focus on systems development, connections research, and novel elements can make great strides in designing structures to be rapidly assembled and disassembled.

Conclusions

At the end of the first decade of the 21st century the wood-based composites industry is faced with dramatic changes in dynamics of the marketplace, which has brought new challenges and opportunities. The way the researchers and the manufacturers respond to these challenges will influence both the performance and viability of the composite materials. The pertinent issues range from resource availability, energy needs for production, global markets, and current shifts in the domestic building industry. It is likely that composites will continue to play an increasing role in building construction, but in order to succeed the industry must embrace innovation and continued development as a permanent self-sustaining process. With the increased reliance on new materials, research must be directed to understand and control durability issues in materials with a limited history in the field service. Hybrid composites may provide some novel approaches to these problems if progress continues. Attention must be given to continued development of pre-engineered building components and modular systems to facilitate resistance to complicated load systems as well as rapid construction and proper code compliance. A systems approach to materials and structural design will provide large gains in building systems that will be realized in building performance, construction, and deconstruction.

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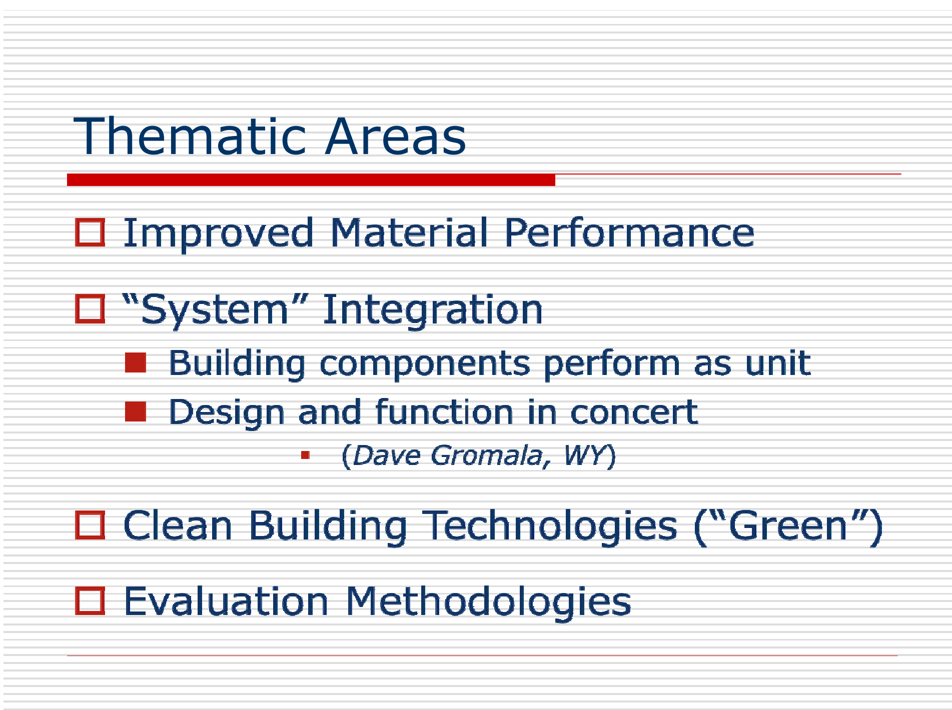
Session Summary

Summary Report of Discussion Groups #3, 11 & 19 on Advanced Materials

Presented by

Michael P. Wolcott (Facilitator)

Lech Muszynski (Scribe)



Summary of recurring themes

Goal:

- Need to improve the performance of wood-based composites

Discussed solutions:

- Durability and serviceability
  - load, moisture, temperature, biological, UV, etc.
- Mechanical performance
  - strength/stiffness AND ductility/energy dissipation
- Uniformity and homogeneity
  - narrower property distributions
  - promote confidence when specifying

Summary of recurring themes

Goal: cont…

- Need to improve the performance of wood-based composites

Discussed solutions: cont…

- New (as opposed to improved) materials that are:
  - "multi-attribute"
  - high performance … but balanced
  - dimensionally stable
- Smart Materials
  - sense: temp, moisture, load history, capacity
  - provide feedback to user or inspector (colorimetric)

  (recurring example: promise of wonder nano-materials)

Summary of recurring themes

Goal:

- "System" integration

Discussed solutions:

- Hybrid (multi-material) systems
  - Continuity among components (performance)
  - Promote cost and use
- Fastening/connector systems designed for:
  - Integrated connectors
  - Constructability (rapid field assembly)
- Design for Deconstruction
    - Reuse, Reconfiguration, and Recycling

Summary of recurring themes

Goal: cont…

- "System" integration

Discussed solutions: cont…

- Materials compatible and ready for integration with clean technology options (e.g. solar panels)
- Pre-fabrication for rapid assembly or
- Flexible manufacturing:
  - 3G (*extrusion, pultrusion, roll forming)*
    - Continuous, produced shape, low capital cost
  - Materials for on-site manufacturing
    - Cast in place (*wood Readi-Mix*)

Summary of recurring themes

Goal:

- Clean Building Technology ("Green")

Discussed solutions:

- Improved environmental footprint
  - Reduce CO2
    - Lower manufacturing energy (*drying, pressing*)
    - Reduced resource dependence
    - Carbon offsets through bio-refinery approaches
  - Improve Indoor Air Quality (IAQ)
    - Low emitting resins/coatings
    - Bio-based adhesives

Summary of recurring themes

Goal: cont…

- Clean Building Technology ("Green")

Discussed solutions: cont…

- Life Cycle issues:
  - Recycle Content & Recyclability
    - Use of recycled materials in composites
    - Make composites more recyclable
  - Recycle resources
    - Mixed construction & demolition (C&D) waste
    - Material separation for C&D waste
    - Recall "Design for Demolition"

Summary of recurring themes

Goal:

- Evaluation Methodologies

Discussed solutions:

- Standardized code acceptance process
  - standard process
    - product introduction, growth and maturity
  - performance based criteria
    - application oriented
    - material-agnostic
  - international (trade units)

Summary of recurring themes

Goal:

- Evaluation Methodologies

Discussed solutions:

- Reliable design methodology
  - Modeling for virtual prototyping
- Price-Performance Evaluation
  - Environmental footprint
  - Structural performance
  - Cost
  - Substitution

Connection to the global drivers

- Sustainability
- Economic impact
- Resource base
- Global competitiveness

Summary Paper

Wood Engineering Challenges in the New Millennium: Critical Research Needs
Materials and Wood-Based Composites *aka "New Materials"*
Summary of sessions #3, #11 & #19

Prepared by Lech Muszyński (scribe) & Michael P. Wolcott (moderator)

Identified research goals

The discussion in sessions concerned with Materials and Wood-Based Composites (or "New Materials") focused on four identified research goals:

1. To improve the performance of wood-based composites
2. To strive for building material system integration
3. To emphasize "Green" solutions
4. To remove barriers to innovation and competitiveness

Discussed solutions:

The following is a summary of themes recurring during the group discussions as proposed critical research needs in order to achieve these goals.

1. In order to improve the performance of wood-based composites the research should focus on:

- ☐ new (as opposed to improved) materials that are:
  - ■ Smart (with embedded sensors that allow recording: Temp, RH, load history, residual capacity; or include colorimetric condition indicators)
  - ■ *Multi-attribute* (address multiple issues at the same time)
  - ■ High-performance or optimized for performance
  - ■ Dimensionally stable

  (the recurring example was the promise of "wonder nano-materials")
- ☐ Durability and serviceability (in all imaginable aspects of durability)
- ☐ Improvements in strength, stiffness AND energy dissipation (smart connectors?)
- ☐ Increased uniformity and homogeneity (narrower property distributions) promote confidence when decisions on material specifications are made

2. In order to achieve greater material-system integration the research should focus on:

- ☐ Hybrid (multi-material) systems
- ☐ Seamless system continuity (in terms of performance)
- ☐ Integrated connectors
- ☐ Fastening/connector systems designed for:
  - ■ constructability (rapid field assembly)
  - ■ in-service reconfiguration
  - ■ deconstruction
  - ■ recycling
- ☐ Materials compatible and ready for integration with green technology (e.g. solar panels)

- ☐ Pre-fabrication for rapid assembly or
- ☐ Flexible manufacturing:
  - ■ Materials for on-site manufacturing (e.g. casting, extrusion, pulltrusion etc.)

3. Emphasis on "Green" by focusing the research on:

- ☐ Reducing environmental impact of the manufacturing process throughout the life cycle of materials (manufacturing, service and post-service life)
- ☐ More holistic approach to material design and manufacturing: Develop integrative evaluation of tradeoffs and optimization guidelines to balance:
  - ■ footprint,
  - ■ structural performance,
  - ■ durability and
  - ■ cost
- ☐ Bio-refinery approach to manufacturing ("whole wood composite")
- ☐ Minimize the net energy input in the manufacturing process (drying, hot pressing etc.)
- ☐ Bio-based adhesives
- ☐ End of life cycle issues:
  - ■ Use of recycled materials in composites
  - ■ Recyclability (utilization of mixed construction and demolition waste streams)
  - ☐ Whole house recycling
    - ■ Material separation and recycling at the demolition site
    - ■ Developing composites that utilize mixed demolition waste (without necessity of sorting)
    - ■ Demolition separation techniques (elimination of hazmats & toxic waste)
  - ☐ Design for deconstruction (beyond re-use)
    - ■ Design for disassemble and re-use
    - ■ Integration of material & fasteners
    - ■ Developing standards (so that proprietary components may work together)
    - ■ Rapid re-configuration of the house integrated in the design process

4. Remove barriers to innovation and competitiveness

- ☐ Standardized code acceptance process
  - ■ specify standard process for product introduction, growth and maturity
  - ■ streamlined, performance based (material-ignorant) criteria
  - ■ end use oriented
  - ■ international (at least within the trade boundaries)
- ☐ Reliable design methodology (virtual prototyping)
- ☐ Connection to the global drivers
  - ■ Sustainability
  - ■ Economic impact
  - ■ Resource base
  - ■ Global competitiveness

PERFORMANCE OF WOOD STRUCTURES

POSITION PAPER

Performance of Wood Structures

J. Daniel Dolan
Department of Civil and Environmental Engineering
Washington State University
Pullman, WA 99164-2910

Vikram Yadama
Department of Civil Engineering
Washington State University
Pullman, WA 99164-2910

Abstract

Upon review of previous position papers concerning timber structures, one is struck by the historic narrow focus of the discipline in that the focus has been on the individual connections and members or of a "systems" concept which focuses on the analysis of the structure and the design of sub-assemblies. However, if one looks at the influence of the other drivers highlighted in this workshop (Green Building, Hazard Mitigation, Advanced Materials, Innovative Systems, Durability, and Maintenance and Rehabilitation) the scope of issues facing timber engineering from a performance point of view becomes tremendous. The future buildings and other structures constructed using timber will continue to follow the current processes for most residential construction. However, commercial and light-industrial construction is where the potential growth for the timber industry lies. Also, while the residential sector will evolve with the introduction of new composite materials, and an increased demand for energy efficiency and higher performance to mitigate economic losses due to natural and other hazards, the use of wood in the other sectors could be expanded if the tools are developed to assist the designer(s) in using wood in forms and locations that augment the design and atmosphere of the space.

The objective of this paper is to collect and communicate some of the perceived needs in research that will enhance the performance of buildings constructed of timber through the next decade. This paper is not intended to be an error-free crystal ball prediction, but rather, it will jump-start a discussion of the topic and possibly provide a mechanism for the participants in the discussion to view the potential for making significant changes to the direction and focus of research over the near and medium terms.

Drivers for Change in Timber Structures

The drivers for change in timber structures are for the most part societal driven. There is a growing desire to have buildings be more environmentally friendly, which implies that the carbon footprint and life-cycle pollution impact of the structure be minimized, which is the goal of "green" building practices. At the same time, the public is desires to have structures that are durable, yet maintenance-free and environmentally benign. Finally, insurance companies and governmental leaders are reaching the conclusion that the concept of acceptable levels of damage might not be affordable any longer. These drivers end up highlighting that the focus on structural performance can not be conducted in a vacuum. The focus areas of Green Building, Hazard Mitigation, Advanced Materials, Innovative Systems, Technology Transfer/Education, Durability, and Maintenance and Rehabilitation all support this focus area, and Structural Performance is the focus area that combines the outputs form all the other drivers and tries to address as many of the desires of the public, business, and political leaders.

It is pretty clear that while innovations in structural form and new composite materials will continue to impact the residential market, and while the residential market is dominated by light-frame wood construction (~95+% of all residential buildings in Canada and United States), commercial construction is the area of building construction that represents the best potential for increasing the use of wood in construction. McKeever et al. (2003) found that only two percent of the structural lumber and six percent of the structural panel products produced was being used in commercial low-rise construction. This position paper will highlight a need and a potential solution to improve the use of timber in this market.

Green Building

The term Green Building implies energy efficiency, low levels of construction debris and pollution, low impact on the environments for a life-cycle analysis. This is one of the stalwarts of the sustainable design movement. The current condition of the building codes and design standards produces a conflict between the energy and structural provisions, in that the energy code pushes for more insulation and energy efficiency which typically results in non-structural sheathing products being substituted for structural sheathing, which weakens the overall structure. This driver is pushing the situation into a need to develop new composite materials and innovative structural systems that allow for higher insulation levels while maintaining or improving the strength and stiffness of the structure. We propose that this can be achieved with wood-strand or natural fiber based composite technology. As basic constituents of a composite, strands provide the needed aspect ratio and capacity to withstand high intra-particle shear stresses. These attributes along with optimum manufacturing parameters are necessary to design a structural wood composite using small diameter timber that is sustainably grown. For example, a light-weight structural sheathing panel with core that allows air flow could provide necessary structural integrity (high specific stiffness and strength) as well as needed insulation and a breathable skin. Climatically relevant building designs will have increasing need for such materials.

Hazard Mitigation

Historically, society has been willing to accept a certain level of risk of failure that translated into design philosophies that implied that there would be a minimal level of damage to the structure in moderate events and potentially high levels of damage in design level events as long as the structure did not collapse and kill the occupants. However, beginning after the 1989 Loma Prieta Earthquake, 1992 Hurricane Andrew, 1994 Northridge earthquake, 1995 Kobe Earthquake, and 2005 Hurricane Katrina, insurance companies and governmental leaders began to question the economic ability to sustain the high levels of loss associated with these types of natural hazards. There is an increasing call to make structures stronger and less prone to damage. This will be a challenge for timber engineers to develop methods of design to minimize the deformations and maximize the water durability that drive the damage levels in timber construction. If imposed with today's methods of design and construction, the cost of construction will rise significantly. To address this demand, new materials and structural systems will have to be developed with changing raw material resources that have other demands such as bioenergy and biofuels.

Advanced Materials

Advanced materials is one of the potential solutions to some of the demands that are being imposed on the structural performance. New materials are being developed that address the desire for green building (carbon sequestering) and improved energy efficiency. The need also implies that the new composite materials need to be structurally sound if traditional structural products are to be replaced with the improved materials.

From another point of view, few designers (architects and engineers) like to design structures utilizing a single material. However, researchers and industrial sponsors have traditionally "circled the wagons" to fend off encroaching raiders from competing products that try to raid market share. Therefore, virtually all design tools focus on a single material and make blending material in hybrid structures difficult at best. Most material interest groups do not want to admit the weaknesses associated with their product and focus on only the strengths. This needs to change, especially if the wood industry wants to make significant inroads into the commercial and light-industrial building market. These buildings are constructed of multiple materials and it is up to the designer to develop how the different materials should interface. With the lack of training, this opens a huge potential for the misuse of wood. If the timber engineering community were to develop tools and guidelines on how to design structures to utilize the strengths of timber while addressing the weaknesses, unique and pleasant structures could be designed, while increasing the use of timber. The public and designers have consistently indicated that they enjoy the warm feel and noise abatement qualities of wood, but the designers often place timber in situations that insure failure due to their inexperience with the material. Proper guidelines and design aides would dramatically improve the proper use of wood.

Construction designs utilizing hybrid materials will also face the challenge of connecting dissimilar and incompatible materials. Variations in material properties, including behavior under changing moisture and thermal conditions, will pose difficulties. However, these difficulties can be overcome with innovative connection designs and new sub-system designs. Innovative coupling joints made with light weight metals such as aluminum and titanium can be utilized to join composite wood members instead of traditional fasteners such as nails, screws, and bolts. Novel hybrid processes that modify, combine, and/or merge existing composite manufacturing techniques could lead to solving some of these hurdles with fastening of dissimilar materials by enabling novel net shape processing. These novel processes if designed properly could also contribute to sustainable manufacturing systems through reduced energy demands and emissions. These environmentally benign manufacturing systems will enable efficient processing of available raw materials leading to reduced wastage. This demands a paradigm shift in how we manufacture and design, specifically product design, manufacturing parameters, and structural design have to take place simultaneously with each determining and influencing the other. For example, desired attributes and functionality of a wood-plastic composite end product have to be considered in designing a die and formulation.

Innovative Systems

Innovative systems may be the single most important mechanism for increasing the use of timber in commercial and light-industrial structures. Designers are typically at ease with steel and concrete for design, and therefore, continue to utilize these materials in their individual designs. However, if innovative structural systems were to be developed that utilize timber as the main material or as components of hybrid systems, designers would notice and use the system in the future. Space-frames, domes, and arches are the "exotic" structural systems for timber at the current time. As hinted at in the previous section, if one were to take off the blinders of assuming that the only structural form available for timber are round or rectangular sections, the whole universe of structural form opens up to assist in innovation. Currently the wood-plastic composite (WPC) product sector is just starting to take advantage of this. Hollow sections is the primary form that is being utilized, but unique blends of traditional light-frame members and WPC are being investigated. DuChateau (2005) illustrated the option of changing the shape of the sill plate in light-frame construction can dramatically increase both the stiffness and strength of the assembly. This idea is being further improved with current research. However, additional form changes can make dramatic improvements in performance from energy, structural performance, and durability standpoints when one applies similar concepts to the interface between the exterior walls and the intermediate platforms of a light-frame building.

Forintek Canada has also developed a systematic approach to developing innovative systems (Karacabeyli and Desjardins, 2008). While these types of formal processes will no doubt produce many useful structural systems, it is also evident from history that informal efforts that are focused on addressing a particular problem are also effective and will undoubtedly continue to contribute to the innovation of structures. It is imperative that the timber engineering community support both types of efforts to provide useful, economical, and environmentally friendly final products. In addition to the traditional natural and man-made hazards, designers are now being called upon to minimize serviceability issues such as noise and annoying vibrations. All of the innovations need to begin to consider the holistic design of the final product not simply the structural components.

Technology Transfer/Education

Technology transfer and educational efforts are key to the success of the effort to improve the performance of structures utilizing timber. As different innovations are introduced, a concerted effort is required to introduce the innovation to the designers, contractors, and regulators. If any one of these groups is left out of the technology transfer process, the innovation will experience a quick death. The designers are currently clamoring for design aides to assist in avoiding pitfalls associated with designing hybrid buildings. Failures of components such as when timber is placed in a demanding location that produces tension perpendicular to grain cause ripple effects within the design community that make adoption of hybrid structures utilizing wood all that much more difficult. The average designer has never had training in wood design and this causes a direct correlation with misuse of wood as a material. Also, unless the designer has some mechanical engineering background, they forget that moisture needs to be controlled in buildings, or that large swings in temperature cause some materials to expand much more than other materials in the system. Tools that check for these types of issues would help the designers avoid costly mistakes.

No material interest groups develop effective design aides that allow the connection of dissimilar materials. Simple examples of effective connection details that would allow designers to connect wood members to masonry, concrete, steel and other materials, while avoiding active design problems for performance would significantly improve the chances that designers would consider timber as a viable materials to use in combination with the materials they are comfortable using (i.e., steel and concrete.) It is the responsibility of the scientific community, especially the educational institutions, to transfer the knowledge in an unbiased form while providing comprehensive technical information. At the same time, forest products industry should actively participate in research collaborations with universities to maintain a stable growth, be competitive, and advance science. If we assume that the relationship between industries, associations, and research organizations is governed solely by the exigencies of need, such understanding could be characterized as unclear, partial, and regressive.

Durability

While realizing that wood is not always an ideal material or material of choice for all applications requiring greater durability, we should explore and engineer new composites and designs incorporating use of multiple materials to impart greater durability to wood and wood-based composites. There are applications that wood is not the optimal material to use; however, it is also true that new engineered wood composites might be well suited for an application that wood would typically fail. Appropriate and inappropriate applications of wood and wood-based composites should be highlighted.

The general public does not want to have to maintain their structures, and therefore, the wood industry is researching methods to make wood more durable form either fungal or insect attack. Additional considerations for durability improvements are UV exposure and effects on subsequent manufacturing processes. As new materials and structural systems are developed, the concept of durability is important. From a green building or hazard mitigation point of view, durability directly affects the final impact that can be made.

We should explore concepts that mitigate the nondurable aspects of wood and composites through clever designs that either avoid moisture buildup or infiltration. This can be done by engineering hybrid products such as wood composite with thermoplastic capping as well as changes in structural design that physically isolates lignocellulosic material from moisture and decay fungi. If need be, abandoned traditional design concepts such as wider overhangs should be brought back.

Maintenance and Rehabilitation

As stated earlier, the public does not wish to maintain their structures. They wish to build them and use them, but not maintain them. New building performance assessments directly or indirectly take maintenance into consideration, and innovations in timber engineering need to address this issue as well. Treatments or sealants have traditionally been used to reduce maintenance, but with new desires for color durability and other criteria, the issue of maintenance will continue to be one for the community to address. Innovative smart materials that incorporate functionally activated additives should be explored. These can include, for example, biocides triggered by moist pockets or fungal activity, thermal stabilizers activated due to extreme heat exposure, or agents that can cure in-situ to bridge cracks in a seismic event.

Rehabilitation has become a new keyword in the area of structural engineering. Designing for decommissioning or recommissioning has become a design goal in many projects. The ability to upgrade the technology in the building without major costs associated with rehabilitation is important. Improving the longevity of the structure and ability to modify the structure without reducing the safety is becoming a major objective of design. One attempt to address this issue is the "Open Building" concept used in many commercial buildings where the interior partitions can be arranged indifferent forms as the use of the building changes. This concept will pose the challenge of having free standing long spans to create a built environment. Composites with high stiffness and strength will be required for these types of construction.

CONCLUSIONS

Over the past half century, timber engineering has focused on components of structural systems that are essentially completely made of wood. Increased demands on performance (structurally, environmentally, and livability) demands that new approaches be utilized to foster innovation and advancement in the area of structural performance. All of the focus areas that are highlighted in this workshop need to be combined to effectively address the structural performance. Innovation in materials, structural systems, and education will need to be combined to effectively move building performance forward in a reasonable manner. The innovations need to consider the structure as a whole rather than a collage of components, and developments need to avoid optimizing a given product or system to the benefit of that product, but at the detriment of the whole. The design process needs to evolve into a holistic design process that resembles more of the design of an aircraft than it currently does.

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Session Summary & Paper

Summary Report of Discussion Groups #4, 12 & 20 on Performance of Wood Structures

Presented by

Dan Dolan (Facilitator)

Vikram Yadama (Scribe)

Sustainable Design & Construction

- LCA
- Design for constructability & disassembly
- Durability & adaptability
- Multi-objective design
  - structural
  - building physics
  - fire
  - environmental/green
- Drivers
  - Performance of wood structures
  - Green building
  - Hazard mitigation
  - Durability
  - Maintenance and rehabilitation

Development of New Materials/Systems

- Hybrid building systems
- Components and connections
- Interaction and compatible materials
- Drivers
  - Green building
  - Advanced materials
  - Innovative systems
  - Durability

Performance Assessments

- Regulations and metrics
  - LCA (sustainability)
  - Natural Hazards
  - Durability
- Sensors
- Building physics
- Drivers
  - Performance of wood structures
  - Hazard mitigation
  - Durability
  - Maintenance and rehabilitation

Tech Transfer/Education

- Designers
- Trades
- Regulators
- Maintenance education for owner
- Continuing Ed
- Drivers
  - Performance of wood structures
  - Green building
  - Hazard mitigation
  - Advanced materials
  - Innovative systems
  - Tech transfer/education
  - Durability
  - Maintenance and rehabilitation

Emphasis on Green/Sustainable Construction Practices

- Minimize material wastage
- Energy efficiency
- Durability
- Recycling

INNOVATIVE SYSTEMS

POSITION PAPER

Innovative Wood Building Systems

Erol Karacabeyli and Richard Desjardins
FPInnovations, Canada

Abstract

A framework to foster the innovative use of structural wood in building systems is presented. To do this, we need to recognize that buildings are categorized by end-use categories, and the performance attributes demanded within each category have to be balanced as satisfying one attribute generally may compromise another. We highlight several key categories of buildings and, given that the selection of a structural system for a building is generally the main driver for the use of different materials, we identify a number of wood-based structural systems that may be suitable for these categories of buildings. Examples of innovative buildings particularly for mixed-material construction are given. Following a summary of the complexity of codes and standards environment, some examples of recent innovative structural products are highlighted.

Building Categories

Figure 1 shows several building categories by end-use, and also depicts the dominant materials in those use categories. Light frame wood buildings largely dominate single family, and low-rise apartment buildings in North America. Studies show that wood products and systems can also be suitable for many non-residential building applications, but designers generally prefer other materials in engineered structures (O'Connor *et al*., 2003). Structures consisting of structural sub-systems made from a mixture of structural materials offer the greatest potential for wood. Innovative systems combined with design tools, effective codes, pre-fabrication, education and training are necessary to expansion of wood use in those applications.

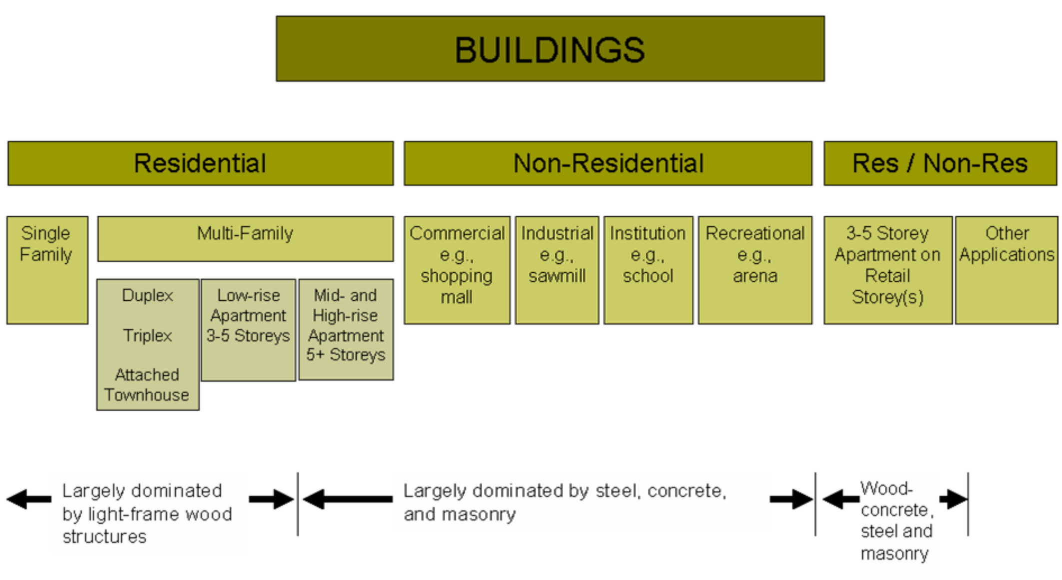


Figure 1 Categories of buildings

Attributes and Factors Effecting Building Systems

The design and construction of a building requires balancing a range of performance attributes demanded by the particular building project and market preference. Figure 2 shows ten factors and attributes that have to be balanced in order to achieve a regulatory and market acceptable design. Solutions for a particular attribute may hinder the performance in another attribute (e.g. acoustical versus structural). Throughout the world, there are many research programs attempting to anticipate the next generation "breakthrough" wood products. While short-term programs aim to build incrementally on existing products (either as a product improvement or a different application), some long-range programs are examining product development at fiber scale or even smaller scale (e.g. application of nano-technology for coating systems). A multi-disciplinary approach in examining how best to allocate resources to balance the competing performance attributes is vital for the successful management of research activities.

Figure 2 Attributes and factors affecting design and construction

Wood-Based Structural Systems

In general, the structural system selection dictates the product specification and, ultimately, whether a particular material is used or not. In Figure 3, wood-based structural systems are grouped under three categories. The first category includes light-frame wood structures, which were originally constructed with the balloon framing technique that later evolved to what we refer today as platform frame construction. Platform frame construction system is the primary technique used for housing in North America, Scandinavia, New Zealand, Australia, and Ireland. Heavy-frame and plate structures are commonly built following post and beam construction techniques and involve the use of heavy timber members such as glued-laminated timber (including composites with Fiber Reinforced Plastics), and other engineered wood products. Massive wood plates composed of nailed or glued wood laminates have started to gain increased use in Europe (Figure 4) and permit longer spans to be reached between supporting beams and columns. Example of structures with mixed systems, either wood-based (e.g. post and beam and light frame in Figure 5) or wood and non-wood based (Figures 6, 7 and 8) present a viable opportunity for increased use of wood products and systems in multi-family residential mixed with commercial, or in non-residential applications.

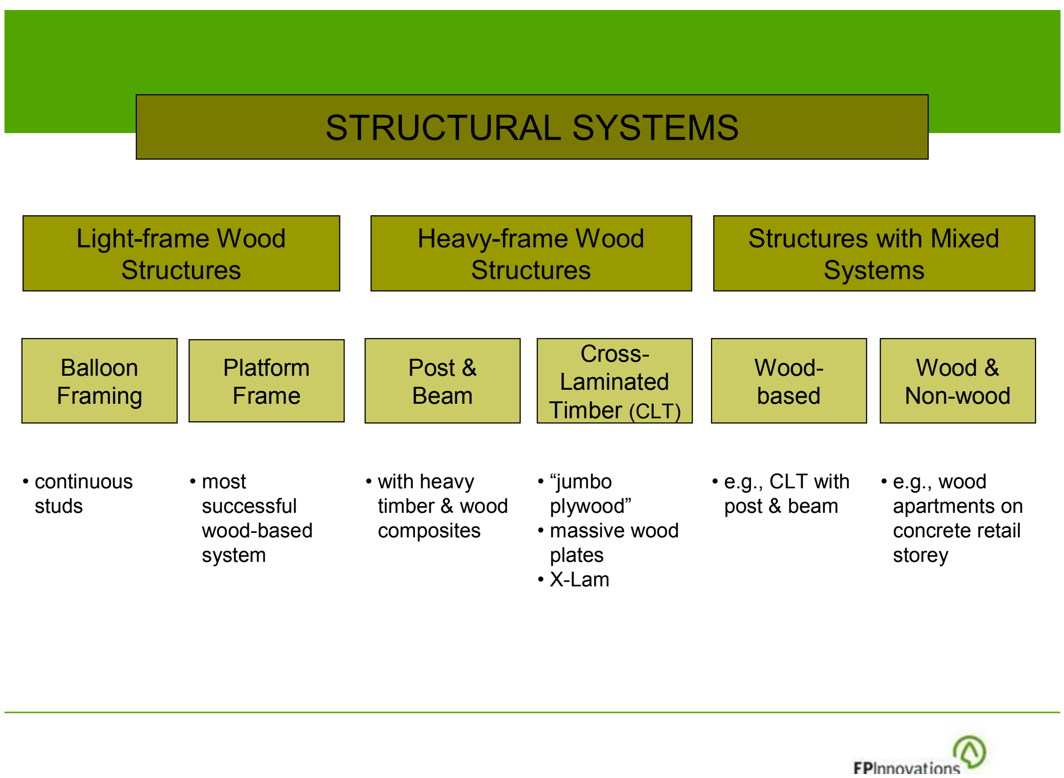


Figure 3 Wood-based structural systems

Figure 4 Multi-Storey building glulam, with cross laminated timber, Limnologen project, Sweden

- Four 8 storey buildings (7 wood on one concrete)
- Glulam and cross laminated timber floors
- Steel rods for wind loads
- Low seismic zone

Figure 5 Mixed light frame and post and beam (e.g. Forintek building, Quebec, Canada)

Vertical load bearing system in the entrance and library with build-up LVL columns with bolts, steel tension cables. Platform frame tall walls the rest of the two storey office/laboratory building.

Figure 6 Mixed (wood steel and concrete). Multi-storey building.
Courtesy of K. Cheung

Pine Square/Pacific Court, Long Beach, CA

- 2-level underground parking
- 4-storey steel-concrete commercial & retail
- 4-storey wood frame living units with sprinkler & fire-retardant exterior walls
- 142 apartments
- AMC 16 theater
- 37,400 sq. ft. retail shops & restaurants

Figure 7. Mixed (wood, steel, concrete and masonry). Fire hall, British Columbia, Canada

Post disaster building designed for greater seismic loads and smaller storey drift. Braced steel frame tower, reinforced concrete moment resisting frame, glulam/steel hybrid truss, nail plywood shear walls and masonry fire wall.

Figure 8. Mixed (wood, steel and concrete) Wrap Construction (wood frame around concrete core). Photo courtesy of Rich Geary.

The most often design has three sides of concrete parking wrapped by wood-frame. The steel/concrete section in the middle of the picture is the walk-in entrance to the wood-frame building
The steel/concrete portion in the middle is the entrance to the building, the reinforced concrete parking structure is on the right.

Complexity of Codes and Standards and Need for Simplicity in Design and Construction

In every market, whether domestic or not, the regulatory environment faced by the designer and builder is very complex. A considerable investment is made by these decision makers to become verse in the ever-changing regulations. "Change" is perhaps the last thing designers and builders would want to impose upon themselves unless there are clear incentives.

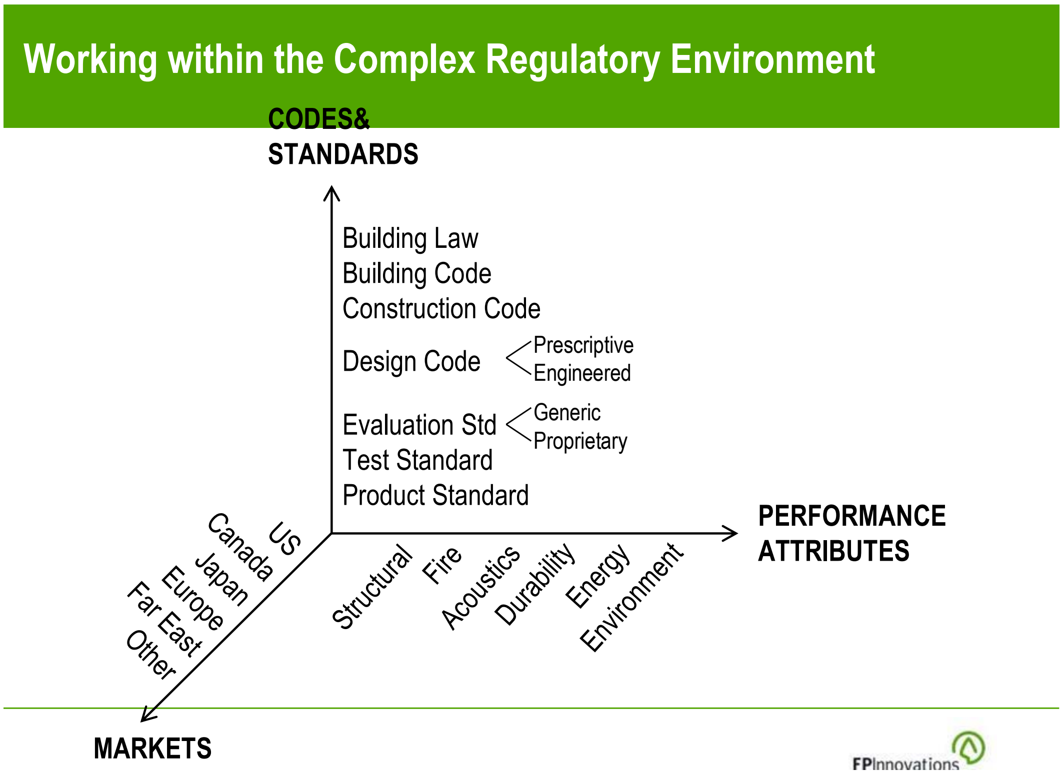


Figure 9 Three Dimensions of regulatory environment

For building design and construction, the codes and standards process strives to keep a balance between public safety and cost. As many designs may include more than one material, it is imperative that wood design standards are aligned with those for other materials to simplify the learning curve for builders and designers. As many proprietary products keep coming on stream, designers would also benefit from specifying a class of product, from which builders could chose from or substitute depending on cost and availability. Such a system would need design tools to assess the impact of or to facilitate the last minute substitutions.

From the construction point of view, three methodologies are being used in wood buildings: "stick" built, panelized, and modular construction. For platform frame wood construction, the panelized method gained popularity particularly in Europe and US. While pre-fabrication is more efficient from material waste, dryness, quality points of view, some builders expressing a return to field fabricated systems which gives them the flexibility to adapt such as trimming at the site. Some proprietary products already provide that kind flexibility. With field fabrication, there is more reliance on site inspection, and inspectors are getting frustrated with the lack information.

The degree and the form of pre-fabrication are basically dependent on the type and size of project. Any innovative system will have to recognize these considerations in order to be used extensively.

Satisfying ever evolving multi-performance demands is a difficult task, and designers and contractors will keep choosing the systems that are readily available, cost effective, easy to design and construct, and environmentally preferred.

Figure 10 Codes and Standards: A balancing act

Effective Connections

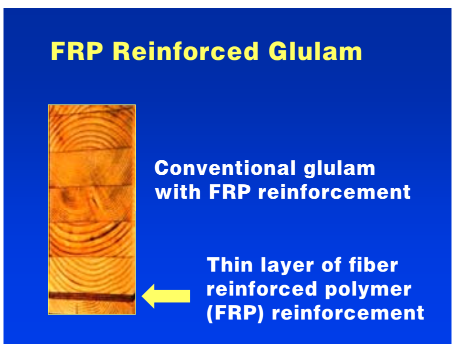
Designing a connection to withstand the structural loads with good durability and fire protection properties is a complex issue that may be additionally burdened by buildability and aesthetic concerns. For wood construction, connection design often includes other materials (e.g. steel hold-down connector anchors a wood member to the concrete foundation). Market studies showed that designers would like to have standard connector information and easy design tools (O'Connor *et al*., 2003). There are number of innovative connection techniques (Moses and Malczyk 2007) emerged in Europe such as self-tapping screws (Figure 11) applied in large timber members with recessed metal plates. There is a need to make simple design procedures and details for off-the shelf standard connections to designers so that they can create more cost effective load bearing systems using wood members.

Figure 11 Examples of innovative connection systems

Fiber Reinforced Polymers (FRP) - *contributed by Tom Williamson*

An emerging technology that has significant potential for increasing the use of wood in large scale structures is to reinforce wood products using high strength fiber reinforced polymers commonly referred to as FRP's. One of the technologies that has been under development for over a decade is to reinforce the tension zone of glulam beams with FRP (Figure 12a). By using as little as 1% of FRP (based on the beam depth) positioned near the tension face of the beam, the MOR of the beam can be increased by 25%-40%. Smaller but still significant increases in beam MOE can also be realized. As such, either the beam size can be reduced significantly or the same size beam can be used to span further and carry much higher loads. The completion of ASTM Standard D7199, Standard Practice for Establishing Characteristic Values for Reinforced Glued Laminated Timber (Glulam) Beams Using Mechanics-Based Models and the adoption of ICC-ES Acceptance Criteria 280, Acceptance Criteria for Fiber-Reinforced-Polymer Glued Laminated Timber Using Mechanics-Based Models have opened the door to advancing this methodology.

(a)



(b)

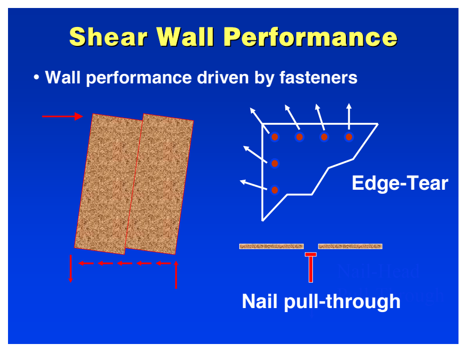


Figure 12 Examples of FRP applications (courtesy of Tom Williamson, APA)

Another related technology is to use a thin strip of FRP positioned around the perimeter of wood structural panels such as plywood or OSB (Figure 12b). In dynamic events such as seismic or high wind loads two common failure mechanisms are edge tear out or nail pull through at the panel edges. By introducing the FRP strip a significant increase in nail pull through and edge tear out resistance is realized. This can lead to much higher shear wall and diaphragm capacities to allow wood panels to compete with steel decks in large nonresidential buildings.

Post-Tensioned Wood-Framed Structures

One design feature that often limits the use of wood in multi-storey structures is the inability to create a rigid or moment resistant frame as is commonly done with steel and concrete. Research being conducted at the University of Canterbury in New Zealand is exploring the development of new post tensioned systems and connections for multi-storey wood-framed timber buildings in earthquake-prone areas using laminated veneer lumber (LVL) and glued laminated timber (glulam). The proposed innovative ductile timber connections are conceptually similar to seismic solutions successfully developed for precast concrete multi-storey buildings. Preliminary quasi-static cyclic tests on frame subassemblies, including exterior beam-column joints and cantilever columns, as well as pseudo-dynamic tests on cantilever columns have shown significant dissipation of hysteretic energy, good self-centering capacity and no appreciable damage of the structural elements.

Midply Shear Wall System

The Midply Wall System is a high performance wood-frame shear wall, developed by scientists from Forintek Division of FPInnovations and University of British Columbia (Varoglu *et al*., 2006). The system is designed to provide superior resistance to earthquake and wind loads. The improved performance is achieved by rearrangement of wall framing components and sheathing used in standard shear walls (Figure 13). Possible applications of the system are a) platform-frame construction where additional capacity is needed (e.g. narrow shear walls); b) post and beam construction (e.g. as an insert to provide lateral resistance); c) seismic upgrading of existing structures; and d) manufactured housing systems directed at areas with high risk of earthquakes and hurricanes.

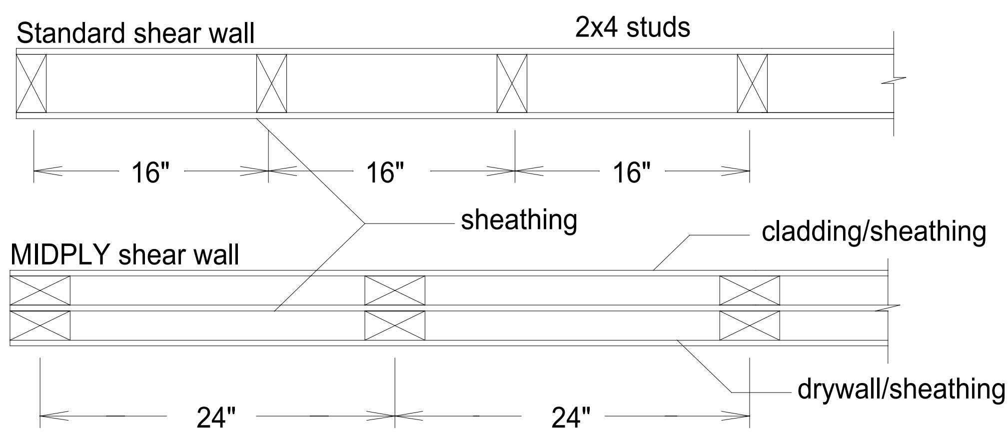


Figure 13 Top view section of the Midply wall system

The superior lateral resistance of the Midply wall system is attained through the following means:

- A wood-based panel is inserted at the centre of a three-panel wall to increase lateral load carrying capacity without increasing wall thickness. Nails fastening this panel to the studs work in double shear (or in triple or quadruple shear, with the addition of exterior sheathing(s)), contributing to the increased capacity of the wall.
- Because the studs are used on the flat, fastener distance to stud edge is increased, and nail pull-through failures are prevented in the middle sheathing, and chip-out failures are drastically reduced. These characteristics lead to excellent lateral load resistance to forces induced by earthquakes and wind.

The structural properties of Midply Wall System have been developed through a systematic testing and analysis program where full-scale test specimens are being subjected to monotonic (ramp), cyclic and dynamic displacement histories. Results have shown that the Midply Wall System possesses much greater load carrying capacity and ductility than standard nailed shear walls. All the pertinent information has been published to facilitate the use of Midply as a high capacity generic wall system (Varoglu *et al*., 2007). Figure 14 shows a site-built application of Midply wall system in a four storey building.

Figure 14 Application of Midply wall system in a four storey building, Vancouver, BC, Canada

Base Isolation and Dampers for Wood Structures - *contributed by John van de Lindt*

In regions of high seismic intensity, applications of base isolation system can be found within concrete and steel commercial buildings, sometimes in bridges. While individual type of isolation system may have different configurations, the protection against ground motion is primarily achieved by providing a layer of low stiffness and greatly increasing the fundamental period of the structure. However, application of such systems to wood-frame structures is relatively rare with most applications appearing to have occurred in Japan. Symans *et al*. (2002) provides an extensive literature review on the use of base isolation and supplemental damping systems for wood-frame structures. In that document, it is noted that, it may be difficult to incorporate base isolation systems in wood-frame structures for many reasons such as the lack of high in-plane stiffness diaphragm at the base level and the cost of base isolation systems relative to that of the wood-frame building itself. In addition, because of the low weight of wood structures, very low friction systems are used which can result in undesirable sliding during strong winds.

The experimental investigation of fluid dampers (Figure 15) incorporated into traditional structural shear walls was conducted in the benchmark tests conducted as part of the NEESWood research project. Additionally, shape memory alloys (SMA) have been applied to wood shear walls in a preliminary study and have shown promise. These systems exploit the very large elastic region in Nickel-Titanium to dissipate energy during ground shaking (van de Lindt and Potts, 2008).

Figure 15   Fluid Dampers

Conclusion

Light frame wood buildings largely dominate single family and low-rise apartment buildings in North America. Market studies show that wood products and systems can also be suitable for many non-residential building applications, but designers generally prefer other materials in those applications. This is often by necessity because of the investment they have to make in customizing tools for costing and design, and in understanding the complex regulatory system. There are many good examples for structures made with a mixture of products and/or systems but they seldom penetrate the mainstream because of the effort required of designers and builders to become competitive when specifying unfamiliar systems. Research efforts are also underway for the development of next generation products and systems. Innovative systems that are simple to design and construct, and easy to combine with other materials and systems along with design tools and codes that are aligned with other materials, and effective education and training will lead to expansion of wood use in those applications.

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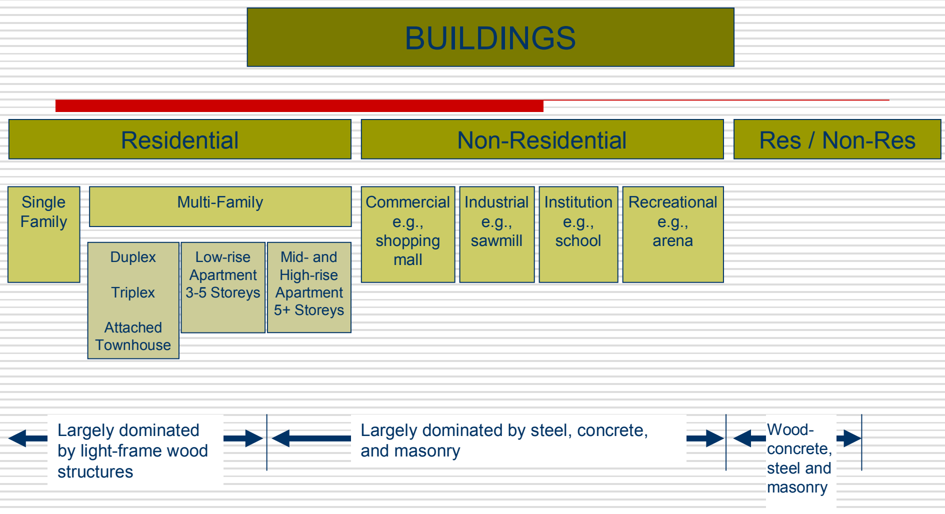
Session Summary & Paper

Summary Report of Discussion Groups #5, 13 & 21 on Innovative Systems

Presented by

Erol Karacabeyli (Facilitator)

R. Desjardins and M. Mohammad (Scribe)



Innovative Systems

- Future Direction for Innovation
  - Design and construct to dis-assemble
  - Simplicity and buildability
  - Align wood design with other material design standards for hybrid construction
    - Design tools: manuals and software
    - LRFD

Innovative Systems

- Future Direction for Innovation
  - Evaluation framework for integration of innovative products in prescriptive and engineered construction
  - Optimum engineering design considering multiple performance demands
  - Move to strength classification system for wood-based products
  - Adapt hybrid construction concepts

Innovative Systems/Assemblies – Research Needs

- Continuous shear wall systems
- Tall wood walls
- Hybrid systems (ensure material compatibility)
- Simplified fire rated systems
- Moment resisting and braced frames
- Composite wood-concrete floors

Innovative Connections Systems – Research Needs

- Link connection performance to system performance
- Connections with self tapping/ drilling screws
- Other proprietary connections
  - E.g. Next generation dowel fastener to prevent splitting, Bertsche-systems, SFS, thermo set dowels
- Ductile/fire resistant adhesives
- Moment resisting connections

Innovative Products – Research Needs

- CLT (X laminated timber)
- Nail laminated panels
- X-ply LVL
- Mid-Ply shear wall
- Multi-purpose/material elements
  - E.g. Solar panels/photovoltaic/insulation panels used as structural systems, innovative building envelope)
- Stressed skin panels for diaphragms
- Post-tension beams/trusses

Innovative Systems

- Expand Light-Frame Construction
- Expand Heavy-Frame Construction
- Mixed System Solutions (Wood-Based)
- Mixed Systems Solutions (Wood & Non-Wood Based)

DURABILITY

POSITION PAPER

Designing Wood Structures for Durability

Rakesh Gupta
Professor
Dept. of Wood Science and Engineering
Oregon State University, Corvallis, OR
Email address: rakesh.gupta@oregonstate.edu

Abstract

Wood is the most common material used in residential construction in North America. It is one of the two oldest building materials in the world (the other one being stone). It is naturally a very durable material. If not attacked by living organisms, wood buildings can last for hundreds or even thousands of years. However, modern day building practices and environmental concerns have raised the issue of durability of wood structures. Even though wood has generally performed well in buildings but sometime these buildings may also experience moisture intrusion over its life. In order to prevent decay due to moisture intrusion, wood buildings need to be designed for durability. This paper discusses status of durability design of wood structures and proposes some of the solutions as research needs.

Introduction

Durability is defined, in MSN Encarta[2], as: '**ability to last:** lasting for a long time, especially without sustaining damage or wear'. This general definition of durability is very subjective: ability to last long time (how long? 5 years or 50 years) and without any damage (no damage or some damage of okay?). Hence, durability has different meaning to different people, and it is important to define durability for wood structures. Here, it is defined as the ability of wood structure to prevent decay due to moisture intrusion.

Wood is an ageless material if the conditions are right. If wood is protected from moisture (MC < 20%), mechanical properties of wood show little change with time (USDA 1999). Still, wood is perceived as a non-durable material because it is assumed that wood decays over time, irrespective of the environment it is in. Other materials (e.g., steel and concrete) are perceived to be durable material even though all materials are susceptible to decay if the conditions are right.

Wood, as a material, generally gets blamed for structural collapse even if the cause of the problem may be inappropriate use (i.e., unprotected wood in ground contact or outdoor use), incorrect design (i.e., improper detailing) or a building mistake (i.e., an undetected plumbing leak in side a wall cavity). A survey (O'Connor 2004) of actual service lives for North American buildings also revealed that there is no significant relationship between the structural system and the actual useful life of the building. This study also found that wood buildings had the longest life spans and most buildings are demolished for reasons other than the physical state of the buildings.

[2] http://encarta.msn.com/encnet/features/dictionary/dictionaryhome.aspx

History has shown that wood is a durable building material because most of the oldest buildings in the world are made of wood. From the ancient temples of Asia to Norway's stave church (Fig. 1), built in the 10th century, wood buildings have passed the test of time (ASCE 1989). Many North American wood frame buildings were built in the 1800s that are still in use. What this means is that if wood buildings are designed, constructed and maintained properly, they would last for a long time. Knowing the idiosyncrasies of the material, wood, and implementing them into the design process is the key to designing durable wood structures.

Figure 1 – Norwegian Stave Church

Moisture is wood's best friend when wood is being made (i.e., when tree is growing) but it may be wood's worst enemy when wood is in use in structural application. Wood can get wet even when it is in use but it must be able to get dry over time. When wood does not get dry over time that is when water becomes a problem and durability of wood is compromised. When wood gets wet and stays wet, it can lead to growth of mold and decay fungi and therefore it is important to detail or design for moisture loads as well. Designing for moisture is as important as designing for fire or structural performance. There are other sources of degradation of wood (e.g., UV, bugs, etc) which do not need moisture. However, this paper mainly focuses on durability of wood structures as it relates to moisture.

Status of Durability Research

Durability research in the area of wood engineering is a new concept even though the related research has been going on for some time (SWST 1982). Until the mid 1980s, there was no discussion about the durability of wood structures. The first structural wood research needs workshop in 1983 (ASCE 1983) had no discussion (no position paper) on durability of wood structures. However, position paper on 'structural lumber: an overview of research view' discussed the influence of end use environment on properties. No specific need on durability was suggested but the following research needs were suggested for end use environment:

> *Duration of load performance evaluation under cyclic ambient temperature and RH and under the cyclic but more random conditions of service. Moisture content and temperature effects of mechanical properties evaluated with time as an additional independent variable. Duration of load performance of treated lumber evaluated in full-size tests because of the influence of chemicals, temperature and time on the structure of the wood. Duration of load tests under continued axial*

and bending stress. A creep model incorporating service environmental parameters.

A few other sessions on other topics also suggested research needs related to end use. Most of the research suggested at the 1983 workshop is specific to end use and some of it has been conducted over the years but there has been no attempt to put it all together in terms of a unified approach for designing for durability of wood structures.

The second workshop (ASCE 1997) again had no specific position/critical research needs paper on durability but improving the durability of wood-based materials was suggested in 'critical research needs: Development of wood-based composite materials'. First time the word 'durability' was mentioned in research needs:

Improve the durability of wood-based materials. Durability evaluations should address long-term performance, including biodegradation, moisture resistance, dimensional stability, creep, creep-rupture, and fatigue.

Some of the research suggested above is still going on at various universities in the US.

Most of the research on durability of wood material/structure has been conducted in Australia since the mid 1990s. Australian researchers have developed timber durability prediction models that could be used in the design of timber construction (Foliente et al 2002, Wang et al 2006, Leicester et al 2006, Nguyen et al 2006). The author doesn't know how much of this has been included in the Australian design codes but the 1997 edition of the Australian timber structures design code (AS 1720.1-1997) had a small section on durability specifying maintenance. It also stated: 'Generally, timber under cover and in well-ventilated conditions and not in contact with the ground or free water, is not subject to fungal attack', emphasizing on detailing the structure properly so that the decay does not start in the first place. Eurocode 5 (1995) simply states that wood should have adequate natural durability or be treated. Canadian (CSA 2001) and US (AF&PA 2005) codes do not have any section related to 'Designing for Durability'. However, both countries have published volume of literature (AF&PA 2006 and CWC 2000) on moisture and wood frame buildings. The author is not aware if other building materials have 'designing for durability' section in their codes, even though other materials are as much susceptible to decay, if not more, as wood if the conditions are right.

How to Design for Durability

The author proposes the following three ways to achieve the durability of wood structures:

(1) Education of designers, builders, contractors and architects

(2) Providing a data base of detailing information for wood structures

(3) Performance based design of wood structures

The author feels that the education is the key to designing durable wood structures because 'knowing the material' is important to designing with any material. Over the past few decades, there has been a steady decline in the percentage of programs actively engaged in delivering wood engineering education and a consequent decline in the number of students getting exposed to wood design in their curriculum. There are a variety of factors that have contributed to the current state of affairs in wood engineering education (Gupta and Gopu 2005). This trend is very disturbing and if unabated could have a negative impact on the nation's wood product industry (Testa and Gupta 2004) and wood structures (Gupta 2005).

The author recommends the following actions be undertaken by the departments engaged in offering wood engineering instruction and by the nation's wood products industry:

- Offer at least on course in wood design, if necessary, at dual level (senior and graduate) to attract both undergraduate and graduate students.
- Sponsor and support a yearly summer institute for university faculty to train them in teaching wood design courses in engineering programs, particularly civil engineering programs.
- Develop and maintain a teaching tool package containing a range of resources, and revise and upgrade it periodically.
- Support wood-related research at universities to train future wood educators and researchers.
- Assist departments to recruit suitable adjunct faculty – when needed – to offer wood design courses and secure source of support for the adjunct faculty.
- Help universities recruit students into wood science programs by providing financial support and competitive salaries upon graduation.

The second most important aspect of designing wood structures for durability is to detail the structures in such a way that if wood ever gets wet in service, it should able to get dry over time, and allowing wood to shrink and swell due to moisture changes in service. This is the approach Europeans have taken (Sagot 1995, Kropf) to designing durable wood structures. A database of dos and don'ts of wood construction would be very helpful for structural engineers in designing durable wood structures for durability. Examples of such details are given in AITC (1984) and Breyer et al (2007).

The third possible way to achieve durability of wood structures is to use the next generation of design procedure - performance based design (PBD). There are numerous factors which must be taken into account in PBD but the main environmental factor to be considered in the durability of wood structures is sources of moisture which can cause all sorts of decay (fungi, insects, termites, etc.) related problem in wood. Most, if not all, durability related problems in wood are related to moisture.

In order to design for any hazard (in this case moisture) using PBD (van de Lindt et al 2008), one has to: (1) characterize hazard (in this case moisture), (2) characterize performance descriptor (or objectives) (3) develop models to describe moisture load and its response, (4) verify the models/procedure developed in (3), and (5) extension to design. In order to complete these five tasks, one has to answer several questions (research needs) as follows:

Hazard characterization: *How should the hazard be characterized? How should the load be developed from the hazard? Return period? What would be needed to develop loads for the performance-based assessment of an engineered wood structure.*

Characterization of performance descriptors: *What performance descriptors may meet the given performance objectives? Should they be quantitative, qualitative, or both?*

Model complexity envisioned: *What level of complexity of the load/response (e.g. numerical models such as FEA) and hazard/performance computations would be required to perform the performance-based assessment.*

Verification of procedure: *What type of evidence would be needed to verify the performance levels achieved are acceptable? This is a particular issue for qualitative assessment. Should acceptance criteria be applied at the component, sub-assembly, or system level? All levels?*

Extension to design: *What would need to be done to extend the performance-based assessment to a design? What steps are needed for specific hazard with references to specific documents and (pre) standard?*

Food for Thought

The questions for the workshop attendees are:

(1) do we really need to conduct research to show that wood is a durable building material when history has already proved that it is a durable building material? If the answer is yes, what research needs to be conducted?

(2) do we really need to conduct research to improve design for durability when other materials just claim that they are durable and never design for durability? If the answer is yes, what research needs to be conducted?

(3) if wood structures can be designed for durability by detailing the structure properly, do we need to do any more research? If the answer is yes, what research needs to be conducted?

(4) What research, if any, needs to be conducted in the broad area of 'durability of wood structures'? Please bring your ideas!

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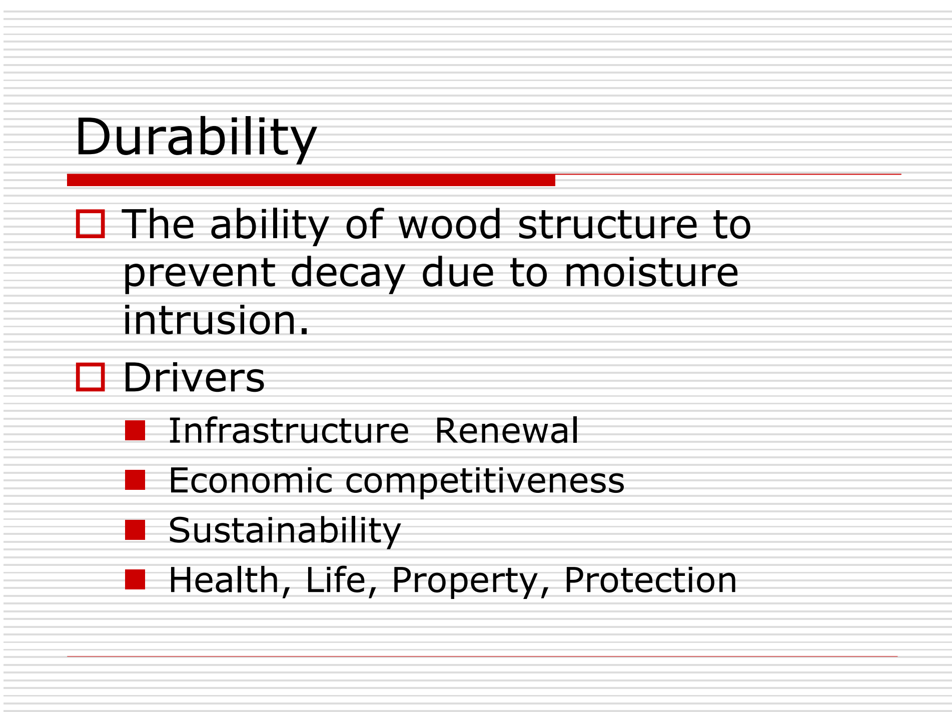
Session Summary

Summary Report of Discussion Groups #6, 14 & 22 on Durability

Presented by

Rakesh Gupta (Facilitator)

Aaron Kjeld (Scribe)



Structure

- Design, Construction, and Maintenance

1. Education/Training
2. Create easy to follow guidelines from one source.
3. Idiot proof construction that applies to all climates. (e.g. New wall design)
4. Homeowners Manual/Classes

Communication

- Engineers, Building Scientist, and Wood Scientist
- Marketing, awareness
- Think like a rain drop
- Four D's – deflection, drainage, drying, and durable material
- Develop design decisions (aids for durability)
- Reliable library on building protection (one source)
- Protection of property in Building Codes
- Need Professional Building envelope science engineers

Critical Research Needs

- All climate wall design
- Product stability (exposure during construction)
- New preservatives (non-toxic, non-corrosive, carbon based)
- Construction process modeling (exposure- time/moisture)

Critical Research Needs

- Define performance criteria.
- Resolve conflicts between Durability and Energy Efficiency.
- Effect of decay on strength properties.
- Quantification of extent of decay in existing buildings.
- Design of wall/roof interface (over hang).

Critical Research Needs

- Moisture indicating products (paint, adhesive)
- Create a quantifiable rating system for new species.
- Better define exposure conditions.
- Moisture load modeling.

Summary Paper

Summary for DURABILITY Breakout Group

2008 ASCE Structures Congress – Pre-Congress Workshop

Wood Engineering Challenges in the New Millennium - Critical Research Needs

Prepared by: Facilitator Prof. Rakesh Gupta, Department of Wood Science and Engineering, Oregon State University

Scribe: Aaron Kjeld, APA

SCOPE AND DEFINITION

The first structural wood research needs workshop in 1983 had no discussion (no position paper) on durability of wood structures. The second workshop again had no specific position/critical research needs paper on durability but improving the durability of wood-based materials was suggested in 'critical research needs: Development of wood-based composite materials'. However, since the 'green' building revolution of the 1990s, durability issues related to wood and other materials have become very important. Hence, the latest wood research needs workshop (2008) had eight sessions and one of them was 'Durability'.

Since durability is very broad issue, for wood structures, it was defined as the ability of wood structure to prevent decay due to moisture intrusion. The main drivers for this topic are: (1) Infrastructure Renewal, (2) Economic competitiveness, (3) Sustainability, and (4) Health, Life, Property, Protection. Three sessions were held, each with a different set of people. The sessions started by asking the following questions:

(1) Do we really need to conduct research to show that wood is a durable building material when history has already proved that it is a durable building material? If the answer is yes, what research needs to be conducted?
(2) Do we really need to conduct research to improve design for durability when other materials just claim that they are durable and never design for durability? If the answer is yes, what research needs to be conducted?
(3) If wood structures can be designed for durability by detailing the structure properly, do we need to do any more research? If the answer is yes, what research needs to be conducted?
(4) What research, if any, needs to be conducted in the broad area of 'durability of wood structures'? Please bring your ideas!

The answers were all over the map.

IMPACT / IMPLICATIONS

There was general sense among all the group members that there is a lot information out there that has to be communicated to the users. The following was suggested:

For Design, Construction, and Maintenance of Structure

1. Education/Training
2. Create easy to follow guidelines from one source.
3. Idiot-proof construction that applies to all climates. (e.g. New wall design)
4. Homeowners Manual/Classes

Communication should include:

- Engineers, Building Scientist, and Wood Scientist
- Marketing, awareness
- Four D's – deflection, drainage, drying, and durable material
- Develop design decisions (aids for durability)
- Reliable library on building protection (one source)
- Protection of property in Building Codes
- Need Professional Building envelope science engineers

RECOMMENDED ACTIONS (Critical Research Needs)

The following critical research needs were suggested by the group members:

- All climate wall design
- Product stability (exposure during construction)
- New preservatives (non-toxic, non-corrosive, carbon based)
- Construction process modeling (exposure- time/moisture)
- Define performance criteria.
- Resolve conflicts between Durability and Energy Efficiency.
- Effect of decay on strength properties.
- Quantification of extent of decay in existing buildings.
- Design of wall/roof interface (over hang).
- Moisture indicating products (paint, adhesive)
- Create a quantifiable rating system for new species.
- Better define exposure conditions.
- Moisture load modeling.

EDUCATION AND TECHNOLOGY TRANSFER

POSITION PAPER

Education and Technology Transfer for Timber Engineering in 2010 and Beyond[3]

Steven M. Cramer
Univ. of Wisconsin-Madison, Madison, WI 53706, cramer@engr.wisc.edu

Dan L. Wheat
University of Texas at Austin, Austin, TX 78712, dwheat@mail.utexas.edu

Robert J. Taylor
American Forest & Paper Association, Washington, DC 20036, robert_taylor@AFandPA.org

ABSTRACT

Engineering educators in the U.S. have witnessed changes both in their students and in their universities. Students' interests, career goals, perspectives, and study habits have changed. As well, universities at all tier levels have put increasing pressures on faculty research productivity; and they, under the pressure of increasing tuition and fees, have often sacrificed some scientific and technical detail to the point of alarm. This suggests that old pedagogies and traditional teaching approaches may not sustain, through the next decade and beyond, some engineering areas; and especially one often viewed as so minor as timber engineering education. These changes, as well as the restricted budget environment and the emphasis on research, present challenges to timber engineering education; but also the opportunity to choose a different path. Reflecting on more than 50 years of university in-the-classroom teaching experience, short course experience to both the consulting world and government agencies, the authors examine the role of universities, industry, and government agencies in seeing that the structural engineering community maintains the professional knowledge base for continued successful design of wood structures and an understanding of their behavior. Several ideas are proposed as well as new educational strategies for all stakeholders.

THE EDUCATIONAL LANDSCAPE IS CHANGING

Previous ASCE wood research needs workshops in 1983 and 1997 did not explicitly include directed discussion on timber engineering education and technology transfer. In the 1997 workshop, discussion did occur on the state of education in several of the breakout sessions and the workshop proceedings describe wood engineering education as being in crisis [ASCE 1998].

So why include this topic now? In the past it was possible to discuss unsolved technical challenges without explicitly discussing the human resource required to solve the challenges, the human resource required to apply the solution and the means of conveyance by which to get the education and technical knowledge to those that need it. Such is no longer the case. What has changed? Since 1997, the landscape for educating current and up-and-coming engineers has

[3] This paper is based on and shares text with *The Changing Nature of Students and Universities: Opportunities for Timber Engineering Education in the U.S.* by the same authors and presented as part of the 2008 ASCE/SEI Structures Congress.

changed dramatically. Based on our experience, we offer some observations and opinions concerning the educational landscape for wood engineering now and into the future. These views are not based on comprehensive surveys of academic departments, but rather on apparent changes in the way the academy is responding to change. The objective of this paper is to prompt discussion and to add other perspectives to the notions that we put forth.

International production of engineering graduates now dwarfs production in North America and Europe. Although debates continue on what counts as an engineering graduate, such debates seem to miss the main point. Universities outside North America and Europe are increasingly offering their instruction in English allowing their graduates to be globally marketable and facilitating English-speaking students to receive education nearly anywhere. To ensure the value of North American engineering graduates in the global market, there are pressures to teach more interdisciplinary breadth and to achieve better teamwork and presentation skills. In short, there is pressure to add value beyond technical depth to North American engineering graduates. The challenge is to accomplish this without compromising the technical depth and rigor necessary for successful engineering. Technology advances and how we use technology seem to change daily. Information flow and communication are now routinely intercontinental and occur almost instantaneously for little or no cost. This communication flow can range from a junior high school student playing an online computer game with competitors across the globe to an entire project team with members in various global locations sharing engineering designs simultaneously. Furthermore, the walls between many engineering disciplines are disappearing. It is now routine for research-oriented universities to hire new engineering faculty who hold terminal degrees in other non-engineering fields. Similarly, research in global challenges, including energy and health care, routinely involve faculty from a variety of disciplines. Successful research centers now almost always include a cross disciplinary team of members with complementary skills chosen to facilitate collaborative research projects.

WHAT ABOUT THE STUDENTS?

Growing up in the midst of these changes is the new generation of university students characterized as the Millenials, or sometimes referred to as the Net Generation (NetGen). Millenials are considered to be those persons born between approximately 1980 and 1994. Many of them see themselves as educational consumers who "want to learn only what they have to learn" in "a style that is best for them" -- and that usually does not mean listening to a professor lecture, as reported in the Chronicle of Higher Education by Richard T. Sweeney, university librarian at the New Jersey Institute of Technology [Carlson 2005]. This generation of students is tech-savvy and will constantly multitask. Study is routinely combined with an on-going text messaging conversation and an iTunes® playlist. They consider their time to be their own and will invest their time only where it will produce a perceived benefit. Whereas a previous generation of students would attend lecture because they had registered for a class and knew that attendance was expected, many Millenials will attend only if they feel it is critically important, and their schedule is otherwise free. Looking at the subset that are engineering students, the Millenials will also be characterized as one with higher standardized test scores, but with a need to improve communication and teamwork skills, and a desire to improve hands-on skills . Mixed in with this generation at many institutions are growing numbers of nontraditional students who become classified as such because of significant differences in age and life circumstances compared to the student majority.

Not everyone agrees with these characterizations. The Chronicle of Higher Education reports contrarian viewpoints that say catering to a particular generation's unique characteristics is overblown and simply contributing to the demise of higher education [Carlson 2005]. These combined traits also have included characterizations of a lack of patience, a lack of discipline, and a short attention span; there is no objective in this paper to characterize this generation as inferior to others, especially intellectually. Clearly there are dangers of oversimplification when providing global labels to a broad group of students. In fact, many readers will recognize these students as their own children and a simple product of the world they are inheriting. With more than 50 years of combined classroom experience, we posit that these evolutionary changes may be profound and, combined with the other world changes described above, hold very significant warning signs for those who think engineering education can remain static.

Given the changes that we notice in the learning styles of today's students, do we customize the education of the Millenials to meet their needs; do we *customize the Millenials* in an attempt to force them to learn the old way; or do we do nothing? We think that doing nothing has to be taken off the table. If we *customize the Millenials*, then the ostensible outcome could be students who simply do not learn even a fraction of what faculty expect and industry demands. This in turn can lead to changes in course content to try to achieve at least a portion of learning goals – e.g. drop the theory and just cover basic engineering design.

As early as 10 years ago, Duderstadt [1997] described a future scenario where faculty will "set aside their roles as teachers and instead become designers of learning experiences, processes, and environments. Further, tomorrow's faculty may have to discard the present style of solitary learning experiences in which students tend to learn primarily on their own through reading, writing, and problem solving." Yet, there are some students who still prefer to learn this way. Instead for the majority of students, "faculty may be asked to develop collective learning experiences in which students work together and learn together, with the faculty member becoming more of a consultant or a coach than a teacher." Naomi Baron, an American University linguistics professor, reports faculty members who used to be considered excellent teachers because of their engaging lectures are now described by students as "sooo boring." [Carlson 2005]. Accepting these observations as accurate, then effective teaching techniques in a new approach for Millenials should include:

1) active engagement by a variety of methods,
2) delivery of informational content via technology and the internet to allow study and access at any and all times but combined with direct faculty interaction at fixed times,
3) realistic case studies which students will immediately recognize as relevant,
4) experiential learning experiences that may also include a service-learning component.

The pedagogical differences in the traditional lecture approach versus the new approach are extreme, and the efforts and investments to adjust are not trivial. One view of the new versus old is expressed in Figure 1, where Tapscott shows the continuum in learning technologies from broadcast to interactive learning. Broadcast learning is focused on the transmitter or teacher who broadcasts common information to a passive group where as interactive learning is focused on the student who gets a customized active learning experience on their own schedule. While instruction historically has followed the old model of broadcast learning, the Millenials seek interactive learning. Various North American institutions and individual course instructors find themselves in the transition from left to right as shown in Figure 1.

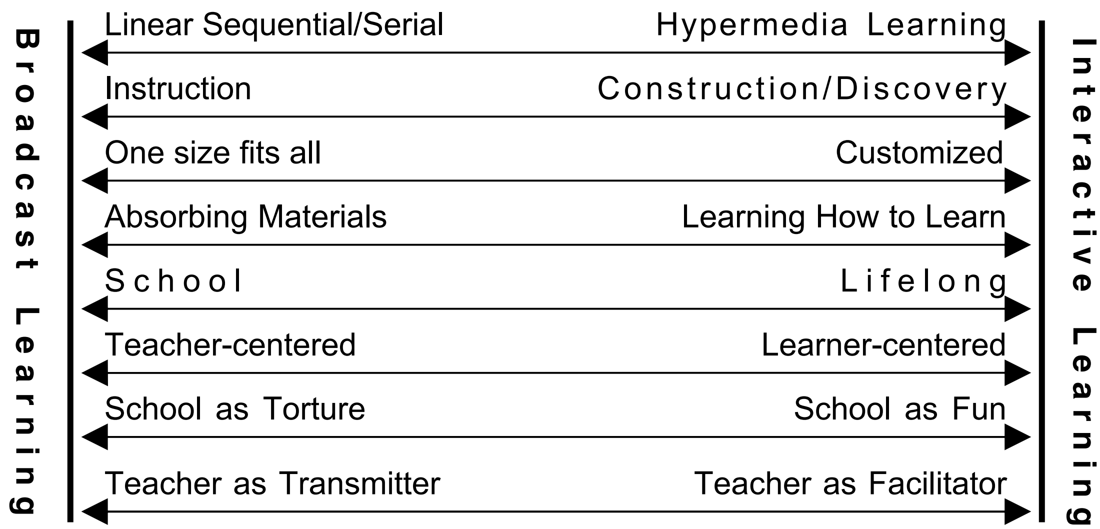


FIGURE 1 - THE TECHNOLOGIES OF LEARNING-FROM BROADCAST TO INTERACTIVE [AFTER TAPSCOTT 1998]

WOOD STRUCTURAL ENGINEERING EDUCATION AND TECHNOLOGY TRANSFER

So how can, how should, and how will, education and technology transfer in wood structural engineering adjust to these changes during the next decade? We use the terms "education" and "technology transfer" to describe a continuum of education and information conveyance experiences. On one extreme engineering education as offered through formal degree programs fulfill several purposes including development of critical thinking skills, technical problem solving skills, a broad education which places engineering in a societal context and a conveyance of engineering design information. Engineering design information changes with time and the practicing engineer must frequently update this part of an education. It is the other components of education which are expected to endure. Technology transfer on the other extreme represents in the wood engineering context the conveyance of current design information. Technology transfer can be achieved through post-formal degree programs, books, websites and on-the-job training.

Despite the prevalence of wood construction for decades, wood engineering is only an elective niche offering in most engineering curricula – almost an afterthought. It sometimes is packaged with other topics such as masonry or prestressed concrete into a single course. In a cut-back mode, elective courses such as this are the most vulnerable to elimination. Multiple undergraduate courses in wood structural engineering are a rarity and a second course, if it exists, typically is offered only intermittently. However, a few graduate programs offering a suite of wood engineering courses still survive, as long as the current institutional faculty concentration to teach them is present. The future challenge is not simply to present material so Millenials can understand it. The future is more uncertain than that, and is based on economic drivers in higher education.

The decision by higher education institutions to invest in wood engineering education is complicated by competing needs and opportunities. These considerations include: availability of research funding, competing curricular needs, job-market for graduates, and industrial drivers in the local or state economy.

Let us first consider a hierarchy of higher education institutions consisting of:

- **research universities**, that is those in the so-called doctoral-one category plus the other research oriented universities that happen not to have that label;
- the **four-year universities,** which are mainly BS-degree granting institutions, but which may have master's degree programs; and
- the **two-year colleges** that grant mainly associates degrees.

At research universities, the decision to invest in faculty to teach wood engineering is impacted by the opportunities for faculty to engage in funded wood research by which students, laboratories and a portion of faculty salary are paid by the research grant or contract. Promotion of faculty continues to rely upon the success in producing scholarly work, one important metric of which typically requires substantial funding from outside sources. Although funding for traditional wood-related research opportunities have never been plentiful, at present they are very limited and there is no indication this situation will change in the foreseeable future. There are opportunities for new research; for example, those topics related to sustainable construction, but such topics have not garnered a focused research program at this point. In the absence of a major research turnaround, when the current generation of engineering faculty who research and teach in wood structures retires, they are likely to be replaced by faculty in other more viable—that is, more external funding potential—research areas. The opportunities for research funding in developing areas of engineering technology overwhelm those in wood engineering even including those new opportunities that could be mustered in the foreseeable future.

We predict that research universities will move toward teaching wood engineering with adjunct or clinical faculty, as an add-on assignment for faculty whose expertise lies in other specialties, or will simply suspend teaching of the course. Adjunct and clinical faculty are often hired to cover key courses that permanent staff faculty cannot provide. However the hiring of an adjunct is subject to availability of funds (which are almost always scarce) and priority of the needed coverage which is always debated within an institution. We believe the supply of engineers with graduate degrees who specialize in wood engineering has been steady in the past several decades. These numbers are likely to decline over the next decade as the number of research oriented faculty with wood specialization also declines at the relatively small number of institutions where they currently exist.

The picture may be different for four-year institutions. These institutions do not have all the competing demands mentioned above and are particularly sensitive to job market demands. In addition, it is generally accepted at some institutions to hire practitioner faculty holding MS degrees and that have worked in engineering practice. If local market conditions are right, and practicing engineers are available to teach, wood engineering education may continue at this level. It is important to note that many of the four-year institutions are working hard to move into the research university arena, and some of them may develop some of the same hiring strategies as seen in the research universities.

Similarly we may see two-year colleges increasingly teach aspects of structural design even though some in the academy may not characterize it as engineering design because of a real or perceived lack of theory/behavior instruction. Many of these schools have very effective programs in giving their students what they will need in day-to-day on the job. As well, some of these institutions are working with the four-year universities and research universities to provide "feeder" courses and curricula that will allow their students to have automatic admission to the universities. We can envision, and welcome, students coming to the university with some basic structural and even wood knowledge.

A reduction in wood engineering education within higher education will drive the need and the demand for a significant increase in continuing education and related technology transfer efforts. Engineers will continue to receive the enduring elements of an education (critical thinking skills, etc) but will need to add the current design information component of their education in a post-formal degree effort. As indicated above, even now, wood engineering education is not a degree requirement and it can be added to, or more likely eliminated from, most higher education curricula despite the real need for more knowledge about wood in seismically active and high wind areas. The demand for training in wood engineering will be filled by short-duration courses that provide detailed instruction in wood structural design. Some of these courses will be developed for distance delivery, but our experience has been that most practitioners look for a different educational experience in addition to that which can be readily delivered in typical on-line offerings. They look for educational experiences that provide what they need for every day engineering practice. For the instructor, this means covering the wood-as-a-material basics, minimum amounts of theory, a lot more on behavior and learning from failures, and allowing the students to interact with one another and with the instructor to problem solve and discuss unique problems unaddressed by design specifications.

For the student, rather than earning another degree or diploma with an emphasis in wood engineering, continuing education credits (CEC's) are earned over the years as proof of knowledge in the material studied. Practitioners typically list earned CEC's on their vitae, and independent registration entities validate and register their credits, much as a university registers issued degrees. Often CEC's are part of a mandated annual licensing requirement, but it is increasingly common to hear that the real need is to resolve a gap in knowledge from previous learning in traditional formal education programs, or to remain current with design trends, products, and issues. There will always be the need for the latter as the design marketplace is fairly competitive, and currency of design and regulatory professionals is obviously advantageous. In the past ten years, continuing education has been an actively growing area of activity among formal education institutions and trade associations. Post-formal degree programs, both online and live contact, are relatively abundant largely out of need to continually service the practicing design and building regulatory communities wherever they live, 24/7. It is very unlikely that this form of educational offering will decline, especially live contact training. As many continuing education students will tell you, there is no substitute for live interaction with a person of knowledge. For many, it's by far the best learning experience.

Less formal technology transfer has flourished with the growth of the internet. Industry-sponsored websites increasingly offer a wide array of valuable design oriented information.

Manuals and presentations abound on these websites for general design oriented information. This information is sufficient in many cases to allow those with limited knowledge of timber engineering to perform simple component design. This can lead to the erroneous assumption that it takes no special knowledge to conduct wood design and just like the home improvement shows, with a bit of online guidance anyone can do it. It is likely these sites will grow in quantity, sophistication of the design information they provide and the means by which they can be accessed. Care should be exercised so that the online consumer knows the limitations of the information they download.

Residential construction continues to rely primarily on wood structural systems, and wood design technology transfer associated with it is increasingly important. At this writing, the housing market is undergoing painful readjustments, but the ongoing and eventual growth in residential construction in traditional seismic and high-wind areas, as well as in both the refurbishment and growth in the newly-declared seismic and high-wind areas, will necessitate more widespread understanding of "how a house stands up." Most seeking information on the internet and most conventionally trained practitioners lack this knowledge, and as discussed earlier, the traditional university wood teaching resources that stoke the student pipeline that leads to these practitioners' doorsteps are diminishing also. The large pool of practicing structural engineers who have designed steel and reinforced concrete structures for wind and seismic loads will have a chance for expanded business opportunities but not without supplementing their knowledge base. Noting the importance of both in-university and extra-university training, we envision the development of educational strategies and non-degree acknowledgements of education, the skeleton for which may be influenced by public umbrella organizations such as engineering professional societies. Such strategies can lead to expedient training of engineers in wood design, particularly lateral load resistance, and ensure that these engineers can satisfy possible jurisdictionally-imposed design qualifications—as maybe impacted, say, by insurability—within or added to licensing.

SUMMARY

Students, universities, and the world are experiencing an acceleration of interrelated changes that is reshaping educational priorities, education delivery and technology transfer. Wood engineering education will not be immune to these changes. Teaching students will require new approaches that will go well beyond basic blackboard lectures, or simply placing former lecture-based course content on the internet. The educational forums will change as a result of the economic drivers in higher education and new student attributes. Graduate education in traditional wood engineering building design is likely to decline gradually over the next decade with faculty retirements at research universities and at some four-year universities; as well, the incumbent number of course offerings for undergraduates will decline. Some four-year and two-year institutions will likely continue to offer such courses as dictated by the hiring demand and local and state industry priorities. Continuing education programs, including internet-based and off-site and on-site live contact are likely to grow significantly to meet the increasing demand and sophistication in wood engineering building design. Design information available through the internet is expected to grow in quantity and sophistication. It is the objective of this paper to prompt discussion of the changes and to guide collectively our resources and efforts to provide the most effective educational opportunities.

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Summary Report of Discussion Groups #7, 15 & 23 on Education and Technology Transfer

Presented by

Steve Cramer (Facilitator)

Cathy Kaake (Scribe)

Problem Analysis

- Time of immense change
  - Globally
  - Students
  - Universities
  - 1997 Wood Research Needs Workshop
    - Wood engineering education in crisis
  - Strong learner demand and clear need for more educational opportunities

Problem analysis

Role		Challenge
Produce PhD's (future faculty), new knowledge, educate 4-yr engineers	Research Universities (graduate degrees & research emphasis)	Scaling back in wood engineering due to restricted budgets, few research opportunities, fewer future faculty, changing student needs
Educate 4-yr engineers	4-year Degree Teaching Universities	Same budget pressures as above, wood engineering a growth agenda at few schools, changing student needs
Educate 2-yr para-professionals	2–year Degree Colleges	Do not educate engineers & architects
Enhance existing knowledge base	Continuing Education	Growing demand but need baseline education from above to build on
Build on existing knowledge base with updates, specific details	Technology Transfer • Industry Association Websites •Others	Continue to grow, but not designed to provide baseline education

Recommendations

- Revitalize the research agenda
  - Wood engineering needs to become a recognized national need and university opportunity
  - Need to align with larger forces
- Repackage wood engineering education as part of emerging national priorities - sustainability

Recommendations

- Wood engineering education should become more interdisciplinary
- Teaching techniques need to address changing student interests and learning styles
- Need to provide incentives in the university system for wood engineering education
  - Travel funds, etc.
- Need to expand wood engineering continuing education – growing demand and opportunity

MAINTENANCE AND REHABILITATION

POSITION PAPER

Maintenance and Rehabilitation – Assessing and Extending the Life of Existing Wood Structures

Ronald W. Anthony
Anthony & Associates, Inc.
Fort Collins, CO 80527
woodguy@anthony-associates.com

Abstract

Perhaps more than any other topic of these proceedings, maintenance and rehabilitation of existing wood structures incorporates the issues of sustainability; economic competitiveness; health, life and property protection; and infrastructural renewal. But few engineers or architects are trained to address issues unique to existing structures. Further, the educational and research communities are not meeting the needs for assessing and extending the life of existing structures. Research is needed to extend the service life of existing structures, especially in identifying hidden deterioration, designing structural repairs and understanding connection capacity and system behavior.

Introduction

Maintenance. Repair. Monitoring. These activities are in the domain of existing structures. In fact, they are critical to protecting public safety and extending the service life of any structure. Yet they do not receive the attention they warrant because they typically do little to advance the state-of-the-art for construction technology, they do not enhance resumes of researchers in the public or education sectors as much as more fashionable research and they simply are not allocated funds to either improve the knowledge base or the stature of those who work in these areas. It is almost mandatory in the research community to focus on engineered products or innovative construction techniques, rather than on saving or maintaining existing structures.

Existing structures - buildings, bridges, utility structures - are routinely assessed by those ill-equipped with the knowledge or tools to make informed decisions about repair or replacement of wood components. The fields of nondestructive testing (NDT), condition rating, repair techniques, upgrading existing structures, building pathology and health monitoring, and predictive or preventive maintenance provide some knowledge base and tools for making informed decisions. Getting that knowledge, including an understanding of the capabilities and limitations of the tools, into the hands of practitioners is given little attention by the engineering profession, including the wood engineering community. The few courses at universities and limited opportunities for continuing education do not meet the demand for what is needed. But that is a topic of another paper in these proceedings.

The research needs discussed in this paper are not focused on those most likely to either read this paper or participate in the 2008 workshop on Research Needs in Wood Engineering. By reading this paper or attending the workshop, it is likely that you are somewhat aware of the research needs for existing structures. This paper serves as a basis for discussion of how resources should be allocated to address research needs in wood engineering. Of more concern are the thousands of practicing engineers that make decisions every day about the reliability, safety, renovation or adaptive reuse of an existing structure without even knowing that they do not have an adequate knowledge base or the tools to make reliable, informed decisions. Perhaps more than any other topic of these proceedings, maintenance and rehabilitation of existing structures incorporates the issues of sustainability; economic competitiveness; health, life and property protection; and infrastructural renewal.

Relevance of Existing Structures

It is difficult to find data that paint an accurate picture of the relevance of existing structures to the U.S. economy. Most reports provide statistics for a particular usage, such as volume of wood used in new residential construction. Those statistics tells us little about the relevance of wood in existing structures. To give us a sense of wood usage, the Western Wood Product Association (Hill, 1993) states:

> *Repair and remodeling has grown from 28 percent of total lumber consumption in 1986 to an estimated 33 percent for this year. This growth has been so great, in fact, that in*
>
> *1990 and 1991 the lumber volume used in repair and remodeling projects exceeded that used in residential construction.*

Further, the British Columbia Forest Industry Fact Book (1998) states:

> *Residential housing construction consumed 37.5 percent of all softwood lumber used in the United States in 1997. The repairs and remodeling market, including the home renovation market, consumed 30.2 percent of total softwood lumber. Other new construction, including commercial buildings, accounted for 14.6 percent in 1997, while material and handling consumed 9.3 percent. All other accounted for the balance of 8.4 percent.*

More recent data from the Wood Products Council (2005a, 2005b) indicates that of the over 43 billion board feet of lumber used in the United States in 2003, 42 percent was used for residential repair and remodeling. For structural panels, such as plywood and OSB, repair and remodeling used 25 percent of the total used in the U.S., and for nonstructural panels, the number was even higher – 33.5 percent. These few data points from the last 15 years indicate a trend of increasing usage of lumber for the maintenance and rehabilitation of existing wood structures.

Until recently, we did not know the volume of wood used in maintaining or renovating existing buildings. We certainly do not know the volume of wood that is retained or discarded (perhaps unnecessarily) from existing buildings. What we do know is that a significant percentage of wood produced in the U.S. is used for repair and maintenance of existing buildings and the percentage is increasing.

What is even more elusive are statistics about the time spent by professionals on existing structures. However, a discussion with most engineering firms across the U.S. will reveal that a significant percentage of the workload is with remodel/retrofit/adaptive reuse/assessment of existing buildings. Engineers fresh out of universities, with very little exposure to wood as an engineering material and to wood construction practices, find themselves thrown into a world of existing buildings because that is where up to half of the billable projects can be found.

Potential Research Needs – Areas of Focus

In spite of the relevance of wood engineering needs for existing structures there is a noticeable gap between reported research on new materials and structures compared to existing structures. There are numerous publications and symposia where wood engineering research findings are reported. Taking one of those, the World Conference on Timber Engineering, for 2006 and 2008, there are approximately 19 papers that address historic structures, 11 that address joint analyses, 8 on nondestructive testing, 12 on maintenance and repairs, and 7 on "in-situ" experimental testing. Less than 15 percent of the papers and posters presented addressed issues directly applicable to existing structures. Similarly, within the field of nondestructive testing, approximately 15 percent of the papers at the 2007 International Symposium on NDT of Wood specifically address existing wooden structures or materials. Other publications and symposia report even less research activity that has relevance to existing structures, including the ASCE Journal on the Performance of Constructed Facilities or the ASCE Journal of Structural Engineering.

Research needs for existing structures are typically conveyed by practitioners that have questions that arise during the course of their work. The questions cross boundaries between wood engineering, wood preservation, architecture, and construction technology. Within the context of wood engineering, the following topics frequently arise during discussion on existing buildings:

- Hidden deterioration
- Structural repairs
- Connection capacity
- System behavior
- Rating systems
- Impact of alternate uses
- Fatigue
- Replacement material
- Material specification
- Remedial preservative treatments for durability
- Creep
- Construction errors and quality control during construction

This paper addresses the research needs of the first four items. Reference documents and supplemental reading are not listed within each topic area but are provided at the end of the paper.

Hidden deterioration

The detection of hidden deterioration using nondestructive testing (NDT) has been practiced for decades. Unfortunately, detection alone is insufficient to address the concerns of practicing engineers. Quantifying the extent of deterioration is paramount to making reliable decisions about the capability of existing structural wood members to carry required loads. Assessing the potential for future or on-going deterioration is also essential. However, predicting future deterioration is a more global phenomenon that relies on moisture diagnostics or building pathology rather than simply localized quantification of deterioration.

Advances in quantifying deterioration in recent years have brought this capability into the hands of practitioners. The use of resistance drilling has been the primary mechanism for quantifying deterioration. For decades, wood researchers have published papers on the ability of various technologies to quantify the extent of deterioration due to decay or insect damage but the reality is that practitioners do not use those technologies to make decisions about repair and replacement, except in isolated instances. Resistance drilling is the only field technique in practice today that can identify both the location and extent of deterioration. Knowing whether a girder has two inches of sound wood on the tension face or six inches makes a considerable difference to an engineer calculating section modulus of a beam.

While useful in identifying the location and extent of deterioration at a point location, resistance drilling is unable to either provide the ability to rapidly assess an entire structure or investigate inaccessible locations. Rapid assessment is desirable to reduce cost. Although an assessment of a large industrial building with heavy timber framing may take several weeks, the cost of the assessment is a small fraction of the cost of rehabilitating or renovating the building. Nonetheless, engineers, architects and owners often have a desire to do an assessment at reduced cost and within a tighter schedule than is typically feasible today.

Inaccessible locations have presented problems during assessment of existing buildings. The most common areas are beam pockets where timbers bear on masonry walls and where roof rafters or trusses bear on a top plate. Connections are also difficult to assess in-situ, either beam-column connections or timbers connected to other materials. Unfortunately, these are areas where moisture penetrates porous bricks or mortar joints and roof leaks or ice dams provide means of water ingress. Deterioration is often the result. Yet we have no reliable means to locate and quantify this deterioration. Resistance drilling, digital radioscopy and stress wave measurements fail to give us the information needed to determine whether the wood is sound and if adequate bearing exists.

Within the area of hidden deterioration, the following research needs should be considered:

- Develop NDT methods for more rapidly assessing the condition, and if possible, quantifying the extent of deterioration in-situ.
- Develop methods for examining key areas in existing buildings, such as beam pockets, rafter/top plates and connections.
- Remedial treatment efforts within the wood preservation community should be coordinated with wood engineering efforts to ensure that in-situ chemical treatments do not adversely affect the mechanical properties of the wood. For example, use of ammonium phosphates as an in-situ fire-retardant treatment is known to affect wood strength but that knowledge has not made its way into the building conservation community.


Unknown beam condition and bearing area within masonry wall

Structural repairs

There is a general lack of data on structural repairs. As a consequence, practitioners are uncertain what repairs can be implemented. There is a wealth of knowledge about repair of glued-laminated timbers but only limited knowledge about epoxy repairs or timber splices. Yet, epoxy repairs are commonly used to repair section of timbers that have deteriorated. Rarely, except perhaps by timber framers, are timber splices used as structural repairs.

Many epoxy-type repair systems are marketed as structural repairs, sometimes in conjunction with steel or fiberglass rods, sometimes without. Remarkably, little, if any, data exist on the performance of these repair systems on full-size timbers. Material properties are listed for the epoxy separate from the wood properties as though, once combined, the properties of the repair are then known. Simply because an adhesive has a greater modulus of rupture for a small adhesive sample does not mean that once incorporated into a deteriorated timber, that the modulus of rupture of the timber will be the governing factor.

Engineers in the field will often use a steel splice to repair broken or deteriorated timbers. That is, if they leave the timber at all. Most practitioners simply choose to remove the questionable timber and replace it with steel.

Makeshift structural repair using steel strap and plate

Within the area of structural repairs, the following research needs should be considered:

- Conduct tests of full-size timbers repaired with epoxy-type repair systems, both with and without reinforcing rods.
- Expand current research on CFRP-wood products to investigate their potential as in-situ repair systems.
- Develop suitable timber splice repairs for use in significant historic structures.

Connection capacity

Under design loads, seldom do wood members fail in a structure unless they are severely deteriorated. Failures generally occur at connections. Yet we have a wealth of knowledge about wood properties, but not the behavior of connections. NDT techniques were developed to give us information on strength, stiffness or deterioration in the wood. Why? Because those were the questions we could answer. Unfortunately, connections are critical in structure performance, particularly in existing structures that have been subjected to a variety of load conditions, and yet we do not have a reliable means to assess their condition or capacity. Techniques, such as digital radioscopy, can reveal the internal construction of a joint or connection, and even whether voids in the wood or corrosion of metal fasteners are present. But it cannot give us any indication of the capacity of the connection.

Within the area of connection capacity, the following research need should be considered:

- Develop the means of establishing the approximate capacity of in-situ connections.
- Develop connections suitable for fabricating repairs in existing buildings.

Beam-column connection with unknown capacity

System behavior

Much research today focuses on system behavior. Existing structures have systems that were seldom researched or even modeled. As a consequence, we do not have a good understanding of how different materials or assemblies behave. Once a structure has been subjected to loads and environmental conditions, it behaves largely as a single unit. But within that unit are systems – floor systems, wall systems, roof systems – that may involve a variety of materials and assemblies. Building code requirements dictate that the structure behavior be understood, at least to the point where it satisfies some code requirement, such as diaphragm action to resist lateral loads. Lacking the knowledge or tools to satisfy such code requirements, engineers often are overly conservative with their reinforcements or simply decide to replace the entire system with one that they understand.

Within the area of system behavior, the following research need should be considered:

- Develop an understanding of the interaction between timber and other materials when intended to behave as a structural system.
- Develop an understanding of the interaction between systems of timber and other materials and their affect on material or structural degradation.

Beam-column-decking system with limited diaphragm action

Process of conducting investigations of existing structures

It would seem that the process of conducting an investigation of existing structures is straight-forward. That is not the case. Books have been written that describe the mechanisms of deterioration, inspection techniques and repairs for all areas of wood structures. The extent of such a discussion exceeds the scope of this paper. However, an attempt to illustrate issues encountered during a typical investigation of wood components in a building are given in the table below. The elements listed are by no means complete but are presented to acquaint the reader with limitations of current knowledge in the four research needs described in this paper.

Investigation of existing wood buildings

Typical Locations to Inspect	Example of Focus Area	Weaknesses in Current Knowledge/Capabilities	Current Level of Knowledge
wood in ground contact	hidden deterioration	unable to detect with poor access	deficient
wood that exhibits moisture stains	hidden deterioration	rapid assessment not available	adequate
wood with visible decay	structural repairs	lack of guidelines	deficient
floor joists and girders	connection capacity and system behavior	not well understood	deficient
sill beams and plates, particularly when in contact with masonry	structural repairs	lack of guidelines	deficient
top plates	system behavior	poor means of assessment	deficient
attic timbers	system behavior	not well understood	deficient
material interfaces (e.g. wood and masonry), particularly beam pockets	hidden deterioration and connection capacity	unable to access embedded material	poor
crawl spaces and basements	hidden deterioration	rapid assessment not available	adequate
areas of the structure that have been modified	system behavior and structural repairs	lack of guidelines	deficient

Summary

Assessing hidden deterioration in existing buildings is critical to promoting the sustainability of timber as a construction material. For wood construction, including new construction, to have economic competitiveness, we must be able to reliably demonstrate that timber in existing buildings can continue to provide service. In spite of our technical efforts to show this, the fact is that, at most universities, engineers are not taught wood engineering and design. When they are, the focus is on engineered wood products. Once they encounter a project with historic construction (e.g. heavy timber), they are typically ill-prepared to know where to begin their engineering analysis. If we want wood products to be economically competitive, we must make the next generation of engineers comfortable with wood construction, including historic construction materials and methods. Without that understanding, they quickly migrate away from any wood construction.

Existing buildings account for a significant percentage of wood used in the U. S. and time spent by engineers and architects. Understanding the condition and behavior of wood in existing buildings is essential for establishing effective maintenance and rehabilitation. Without such understanding, health, life and property can be at risk. Research on understanding and maintaining existing structures contributes to infrastructure renewal, preservation of our cultural heritage and a sustainable market for wood construction.

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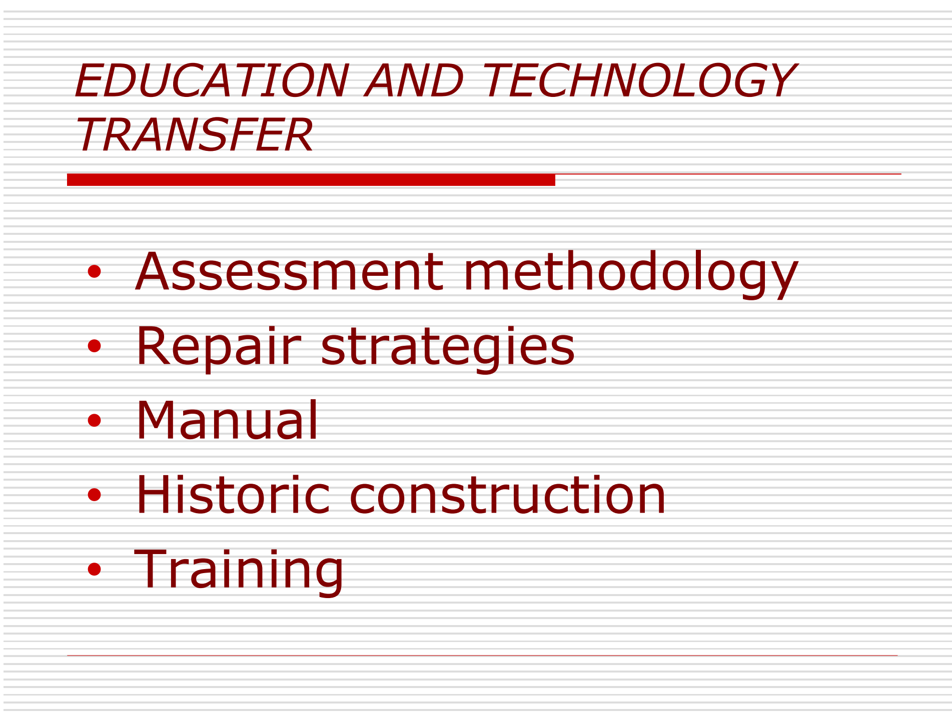
Session Summary & Paper

Summary Report of Discussion Groups #8, 16 & 24 on Maintenance and Rebabilitation

Presented by

Ron Anthony (Facilitator)

Sam Zelinka (Scribe)



NONDESTRUCTIVE TESTING METHODS AND MONITORING

- Detecting and quantifying deterioration
- Determine properties in-situ
- Technology for monitoring structure condition

CONNECTIONS

- Assess performance and capacity

LESSER PRIORITIES

- Post strengthening and repair methods
- Effect of off-grade characteristics
- Effect of chemical treatments
- Maintenance
- Understanding system behavior

POST-WORKSHOP SUMMARY OF KEY RESEARCH NEEDS

U.S. National Agenda for Wood Research
Key Research Needs

1. Green Building
    1. Improve the energy efficiency of wood buildings
    2. Increase/improve the recycling, reuse, and deconstruction practices for wood buildings
    3. Develop optimal value engineering design and construction practices for wood structures.

2. Hazard Mitigation
    1. Develop and implement performance-based approaches for the design of wood structures to better protect life and property from natural hazards.
    2. Validate predictive models of performance using post-hazard inspection data.

3. Advanced Materials
    1. Need to improve the performance of wood-based composites, i.e., durability and serviceability; mechanical performance; uniformity and homogeneity.
    2. System" integration - Materials compatible and ready for integration with clean technology options (e.g. solar panels)

4. Performance of Wood Structures
    1. Sustainable Design & Construction – LCA; Design for constructability & disassembly; Durability & adaptability; Multi-objective design.
    2. Development of New Materials/Systems - Hybrid building systems; Components and connections; Interaction and compatible materials

5. Innovative Systems
    1. Develop next generation wood systems including materials, connections, assemblies, and products.
    2. Develop advanced design and construction methodologies using combined materials (hybrid construction).

6. Durability
    1. Develop methodologies that strike an optimal balance between energy efficiency and long-term durability.
    2. Develop mechanistic load and response models for moisture in wood buildings.

7. Education and Technology Transfer
    1. Repackage wood engineering education as part of emerging national priorities – sustainability
    2. Revitalize the research agenda – Wood engineering needs to become a recognized national need and university opportunity; Need to align with larger forces

8. Assessment and Rehabilitation of Existing Structures
    1. Develop a systematic assessment methodology for existing wood structures, including products, assemblies, historic construction, and connections.
    2. Develop monitoring and nondestructive evaluation methods for performance evaluation, including condition and capacity for existing structures.

BIOGRAPHIES
OF KEYNOTE SPEAKERS
AND AUTHORS
OF POSITION PAPERS

Ian de la Roche, President and CEO, FP Innovations, Vancouver, British Columbia, Canada

Dr. Ian de la Roche became President and Chief Executive Officer of Forintek Canada Corporation in January 1992. Forintek was established in 1979 as Canada's national wood products research institute, and is a partnership of industry, the federal government, and seven provincial governments. It has laboratories in Vancouver, British Columbia, and Sainte-Foy, Quebec, and regional offices in Edmonton, Alberta; Prince Albert, Saskatchewan; and Ottawa, Ontario. It delivers programs in information, technology, and training, which are geared to help the wood products industry increase its productivity, create new value-added products, and protect and extend its markets in North America and around the world. Dr. de la Roche brought to Forintek over 20 years of experience in research, strategic planning, and the building of industry-government partnerships. In his previous positions, he played a key role in the establishment of programs to facilitate commercialization of new technology and the development of joint R&D ventures with industry, government, and universities. During 1990-91, he held the position of Assistant Deputy Minister of Consultation and Communications, Agriculture Canada. He headed up the Communications Branch and was a senior advisor to the Minister of Agriculture Canada. Prior to that, he held the position of Assistant Deputy Minister of the Department of Western Economic Diversification Canada, Saskatchewan. At Western Diversification, he was responsible for the Diversification Fund in the province and was the Senior Federal Coordinator on economic issues. Previous to this appointment, he was a scientist and Senior Research Manager with Agriculture Canada for 18 years. He received a B.S. from McGill University, M.S. from the University of Massachusetts, and Ph.D. from the University of Illinois. He has published over 75 articles, 50 of which have been in the area of plant genetics, physiology, and biotechnology. Committees, which Dr. de la Roche is currently serving on include: President, Forest Products Society; Adjunct Professor, Nanjing Forestry University and Beijing Forestry University; National Forest Strategy Coalition; National Forest S&T Forum; University of British Columbia, Faculty of Forestry, Dean's Advisory Committee; University of California at Berkeley, Faculty of Forestry, Advisory Committee; Forest Products Research Network Forum; Government of Canada, Forest Sector Advisory Council - Sub-Committee Working Group on Science & Technology; and Vancouver Board of Trade, Advanced Technology Task Force.

Ken Skog is Project leader for Economics and Statistics Research Unit at FPL.

Economics research of the unit includes modeling and analysis of the pulp and paper sector and the solid wood sector to evaluate and project the impacts of changing technology, as well as production, consumption, and trade on prices and quantities of wood products and on forest management trends and opportunities. Modeling and projections are done in cooperation with other Forest Service Research Units. These analyses contribute to the Forest Service long-range assessment of forest resource supply and demand required by the Resources Planning Act of 1974 and subsequent legislation.
Statistical research of the unit provides statistical methods to enhance the integrity and efficiency of FPL research. This includes the use of specialized experimental designs to compare the effect of different treatments as powerfully and efficiently as possible, the use of advanced computer intensive statistical methods to incorporate real world complexities, and the use of innovative ways to model research results and predict future performance under a variety of conditions.

Recent personal research includes 1) estimates of wood resources available for biofuels in the Western U.S., 2) preparing guidelines for U.S. entities, including businesses and landowners, to report carbon storage in wood products under the voluntary DOE 1605b program, 3) development of draft international IPCC guidelines for countries to estimate and report carbon stored in wood products, 4) leading a team that prepared reports on socio-economic indicators in the National Report on Sustainable Forests -2004, and 5) leading a team to prepare an assessment of forest biomass use to reduce fire hazard in the U.S. West.

Thomas G. Williamson, P.E.

Tom Williamson is Vice President of Quality Assurance and Technical Services for *APA-The Engineered Wood Association*, and oversees a staff of over 60 scientists, engineers, auditors and technicians involved in all aspects of research, product evaluation and certification for glued composite wood products including wood structural panels (plywood and OSB), glued laminated timber (glulam), prefabricated wood I-joists and laminated veneer lumber (LVL).

Prior to joining APA, Mr. Williamson was Executive Vice President of the American Institute of Timber Construction (AITC) where he was the CEO with responsibility for all management activities of the association.

Mr. Williamson gained extensive experience as a practicing design professional having spent 13 years in private engineering practice as Executive Vice President and Chief Operating Officer of LamFab Wood Structures, a firm specializing in the design and erection of commercial buildings using wood framed systems.

Mr. Williamson represents APA in a number of green building associated activities. He is a member of the Resources Committee of the ANSI committee developing a consensus standard for Green Globes, a green building rating system for commercial buildings. He is also a member of the Resources Committee of the NAHB sponsored ANSI committee developing a consensus standard for a green building rating system for residential construction. He has also presented a number of papers on wood as a green building material at various green building meetings. APA is also a member of the USGBC and has provided numerous comments related to their LEED green building rating system.

Mr. Williamson holds both BSCE and MSCE degrees with an emphasis on engineering materials and structural engineering.

Mr. Williamson is co-editor in chief of the McGraw-Hill *Wood Engineering and Construction Handbook* with the 3rd edition published in 1999. He is also co-author of the chapter on Wood Construction in the McGraw-Hill *Building Design and Construction Handbook*. And he is editor in chief of the *APA Engineered Wood Handbook* published by McGraw-Hill in 2002.

In addition to these handbooks, he has written and presented over 100 technical papers at various meeting and conferences around the World.

John W. van de Lindt, Ph.D.
Associate Professor
Department of Civil and Environmental Engineering
Colorado State University
http://www.engr.colostate.edu/~jwv/
jwv@engr.colostate.edu

Biographical Summary

Dr. John W. van de Lindt received his Ph.D. in structural engineering from Texas A&M University in 1999 and is an Associate Professor of Structural Engineering at Colorado State University. Dr. van de Lindt's research program focuses on coupling nonlinear dynamics and structural reliability during extreme loading events such as earthquake and wind. This includes the development of new nonlinear numerical models and experimental investigations to calibrate those models and support research hypotheses. A related focus was reliability-based design code calibrations for LRFD and performance-based design methodologies, the former focusing on strength-based assessments and the latter developing and applying damage-based and drift-based models. He currently serves as TAC Chair for the Committees on Wood for SEI/ASCE and is leading a special project entitled "The Next Step for ASCE 16: Performance-Based Design of Woodframe Structures". He organized and hosted the *1st invitational Workshop on Performance-Based Design of Woodframe Structures* in Fort Collins, in July 2005. He has served as a U.S. delegate at the 4th and 5th NEES/E-Defense Planning Meeting in Kobe, Japan; and as a U.S. delegate for the 2006 and 2007 Building Experts Committees in Japan and Canada, respectively. Professor van de Ling has organized and chaired over ten conference sessions including a "Performance-Based Engineering of Wood Structures: Perspectives from Around the Globe" at the 2006 World Conference on Timber Engineering. He visited the national Institute of earth Science and Disaster Prevention as a Foreign Expert in Wood Engineering in 2007. Dr van de Lindt led a six person team to investigate the damage caused to woodframe building by hurricane Katrina in 2005. As a result, he participated on the National Science Board's workshop on hurricane science and engineering as an invited participant. He is also leading a five university project entitled "NEESWood: Development of Performance-Based Seismic Design Philosophy for Mid-Rise Woodframe Construction" which will culminate with the world's largest shake table test in Miki City, Japan in 2009.

Michael P. Wolcott
Professor
Wood Materials and Engineering Laboratory
Civil and Environmental Engineering
Washington State University
Pullman, WA 99164
wolcott@wsu.edu

Dr. Wolcott, on the WSU faculty since 1996, is an international leader in the area of wood-based composite research, where his work has led to the development of advanced materials to better withstand aging processes, reduce manufacturing costs and pollution, and provide better performance. He has received more than $18 million in funding from numerous federal agencies, including the Office of Naval Research, the Department of Energy, the USDA, the US Forest Service, and the Federal Highway Administration. He holds three patents for innovative materials and structures from wood and natural fibers. Wolcott has been actively engaged with industry to commercialize his research and has participated in projects for more than 45 companies. He has also received numerous national awards for research excellence, including the prestigious Society of Wood Science and Technology's *George Marra Award* (in 1991 and 1995), and he has been an invited keynote lecturer at renowned international conferences. He is well published in national and international journals focused on composites, polymers, and natural materials and his work is highly cited.

Lech Muszyński
Assistant Professor
Department of Wood Science and Engineering
Oregon State University
Corvallis, OR 97331
lech.muszynski@oregonstate.edu

Dr. Lech Muszyński is an assistant professor in the Department of Wood Science and Engineering at Oregon State University. A native of Poland, he received his M.S. in wood technology and his Ph.D. in forestry and wood technology from the Agricultural University of Poznań. In 1998–2004 he worked in the area of wood composites in the Advanced Engineered Wood Composites Center at the University of Maine. Currently his research areas include mechanical performance of solid wood, micromechanics of traditional wood-based composites, as well as advanced hybrid wood–plastic and wood–FRP composites, with stress on structure–property relations, interface performance, bonding, durability, damage assessment, time-dependent phenomena, and hygromechanical behavior. He teaches physics of renewable materials and bio-based composites manufacturing.

Dr. J. Daniel Dolan, P.E.
Department of Civil and Environmental Engineering
Washington State University

Dr. J. Daniel Dolan is a professor of Civil Engineering and specializes in dynamic loading of low-rise structures. He conducts research on the performance of low-rise buildings and their components when loaded by earthquakes, high wind, and vibration. He has conducted tests on connections, individual members (beams, joists, etc.), and full-scale components (walls and floors). He has also conducted in-situ structural tests on building components to insure performance met the requirements of building codes. Finally, he has developed numerical models that simulate the 2D and 3D performance of buildings subjected to earthquake and high wind loading.

Dr. Dolan participated in the building code process since 1989 in an effort to transfer results from the research community to the building and design codes in the United States, South America, and Europe. He has served on the ah hoc committee for drafting the structural provisions of the International Residential Code (IRC) and has served on the ICC technical update committee for the IRC Building and Energy for four cycles of change, and is now serving on the International Building Code (IBC) Structural Committee. He is also serving as a member of the ICC Ad Hoc Committee on IRC Sheathing Issues and chairs the technical Ad Hoc committee on IRC Sheathing Issues. Dr. Dolan is or has served on several other committees that influence how buildings are designed and built. These organizations include Building Seismic Safety Council, Code Resource Support Committee, National Institute of Science and Technology, American Forest & Paper Association, American Iron and Steel Institute, and Masonry Standards Joint Committee. He conducts training and continuing education seminars for various building departments and professional associations around the country.

V. Yadama
Department of Civil and Environmental Engineering
Washington State University

Dr. Vikram Yadama, Assistant Professor and Extension Specialist, joined the faculty of Washington State University's Wood Materials and Engineering Laboratory. Vikram has a dual appointment of research and extension within the Department of Civil and Environmental Engineering and WSU Extension. His educational background spans the fields of forestry and forest management (B.S. from Iowa State University), forest products and wood science (M.S. from Virginia Tech), and structural engineering (Ph.D. in Civil Engineering from Washington State University). Vikram has extensive experience as a project leader in extension and applied research gained at Mississippi State University, where he held a research faculty position at the Forest Products Laboratory for approximately ten years. In this capacity, he interacted frequently with the wood-based composite industry and furniture manufacturers and provided them with technical assistance. He is an active member of the Society of Wood Science and Technology and the Forest Products Society. His areas of interest are wood-based composites' processing and product development and improvement, structure and property modeling, and material properties evaluation. He also co-chairs the International Wood Composites Symposium held annually either in Pullman or Seattle, WA.

Erol Karacabeyli

Mr. Erol Karacabeyli is a Registered Professional Engineer in British Columbia, Canada, and has over twenty years experience in the timber engineering research field. After receiving his second Master Degree from the University of British Columbia, Erol joined Forintek (now a Division of FPInnovations) as a wood engineering scientist, and over a span of twenty years, became a well-known specialist on seismic performance of timber structures, duration of load effects on lumber, panel and engineered wood products, and connections. Erol is currently the Manager of the Building Systems Department in Western Laboratory of Forintek. The department has over 30 staff comprising of scientists, engineers, research associates and technologists. Erol is an influential member in national and international codes and standards committees whose mandates encompass the safety and reliability of wood structures. For example, Erol is a member of the Canadian Committee on Earthquake Engineering, US Building Seismic Safety Council, the Seismic Task Force of the CSA Technical Committee on Engineering Design in Wood, ISO Technical Committee on Timber Structures, and ASTM. Erol made significant contributions in wood engineering field, and published his findings in over 70 publications (20 journal articles, one book chapter, one encyclopaedia article; one code commentary, two special publications in four languages, and over 50 conference papers).

Richard Desjardins

Richard Desjardins holds a bachelor degree and a Master of Applied Science degree in civil engineering from Laval University in Canada. Before joining the Forintek Canada Corp. team, now FPInnovations, he held a number of positions in solid mechanics research in civil and aerospace engineering. He is a member of the Ordre des ingénieurs du Québec. As a structural engineer, he currently is the eastern region building systems program manager at FPInnovations in Quebec City, Canada, overseeing a group of scientists and technologists working in structural and fire safety engineering, energy efficiency, building envelope, markets and economics, and sustainable building construction. His field of work in research and development focuses on the innovative use of wood products and systems both in traditional residential and the now expanding nonresidential and multifamily construction. He is an active member of a number of codes and standards technical committees in Canada and in North America (e.g., NLGA, ASTM, CSA). He taught the wood engineering courses at Laval University for a period of five years.

Rakesh Gupta

Dr. Gupta's expertise is in the area of Structural Wood Engineering and Wood Science. He is currently an Associate Professor in the Department of Wood Science and Engineering at Oregon State University. The major thrust of his research program is in the area of Timber Engineering and Mechanics. Specifically, in the last few years, his research projects have been in the area of (1) mechanical properties/behavior of wood and (2) behavior of wood-frame buildings and components under lateral loads. He is currently Associate Editor of the Journal of Structural Engineering and has chaired numerous sessions on Wood Engineering at various national and international conferences. He received his PhD from Cornell University and MS from the University of Manitoba in Winnipeg, Canada.

Steven M. Cramer, Ph.D., P.E., F.ASCE
Department of Civil and Environmental Engineering
University of Wisconsin-Madison, Madison, Wisconsin

Dr. Cramer is Professor of Civil Engineering and Associate Dean of Academic Affairs at the University of Wisconsin-Madison where he has been engaged in wood-related research and teaching for 24 years. Dr. Cramer's teaching has included on-campus and off-campus courses in the design of wood structures, structural analysis, materials for constructed facilities, and fire resistant design in building construction. His research has included studies on the system response of wood assemblies, fire and grading of lumber. Dr. Cramer has contributed to structural code and standards development through active roles in the American Lumber Standards Committee, American Society of Civil Engineers, ASTM-International, the Truss Plate Institute and the American Forest and Paper Assoc.

Dan L. Wheat, Ph.D., P.E., M.ASCE
Department of Civil, Architectural, and Environmental Engineering
University of Texas at Austin, Austin, Texas

Dr. Wheat's academic background is structural mechanics, flavored by more practical issues associated with wood. He has been on the faculty of the University of Texas at Austin for twenty-seven years, and in that time, he has published and conducted research primarily in the structural modeling of wood and the testing of light-frame wood floor, wall, and roof systems. He and his students have accumulated some of the only laboratory data in the U.S. on true ultimate strength behavior of full-sized light-frame systems. In addition to testing large scale systems, Dr. Wheat and his students have formulated analytical schemes by which to predict the behavior of these systems; these include both material and geometric nonlinearities required for modeling above the service load levels. Dr. Wheat also has served on numerous national committees and review panels. His teaching includes structural wood design, but also graduate and undergraduate courses in structural analysis and structural mechanics.

Robert J. Taylor, PhD, P.Eng., M.ASCE, Assoc.AIA
Director, Technology Transfer
American Forest & Paper Association / American Wood Council

Dr. Taylor joined the AF&PA as Director, Technology Transfer, coming from his former position as Professor of Structures at the School of Architecture, Montana State University, Bozeman. He holds degrees from Ryerson Polytechnical University, Queen's University, and the University of British Columbia, Canada, majoring in structural/civil engineering and architecture. A licensed professional engineer in his native Canada and former chief building official, he has accumulated over 30 years of experience in academia, industry, and government in highway and building design, consulting, forensics, research, teaching, and administrative capacities. Robert is a well-known speaker, educator, and presenter of wood design education topics, and appears at many seminars and Wood Solutions Fairs nationally every year. With assistance from AWC field staff, Robert creates AWC's educational programs and scripts, as well as online educational materials. Robert has produced many writings and designed many small/medium scale building projects in Canada, USA, Japan, and Korea. His passion for building design has always been in developing innovative ways to use wood towards a holistic design result both at the macro and micro scale.

RONALD W. ANTHONY
Wood Scientist
Anthony & Associates, Inc.
P.O. Box 271400
Fort Collins, CO 80527 U.S.A.
Phone: 1-970-377-2453
Fax: 1-970-377-2469
woodguy@anthony-associates.com

Ron Anthony received an M.S. in Wood Science and Technology from Colorado State University. He earned his B.S. in Forest Management and Wood Science and Technology, also from Colorado State University. Prior to forming Anthony & Associates in 1999, he conducted research and consulted on wood properties and the use of wood in construction applications. Anthony & Associates, Inc. focuses on evaluating the performance of wood in historic structures and conducting forensic investigations. Mr. Anthony's research activities have focused on nondestructive evaluation and materials testing to better understand how wood interacts with other materials and performs over time. His efforts have led to applications of resistance drilling and digital radioscopy for quantifying decay in structural timbers and investigating hidden conditions.

His consulting activities have focused on the application of these innovative inspection technologies for assessment of wood in historic structures, such as Gustav Stickley's Craftsman Farms in Morris Plains, New Jersey; James Madison's Montpelier in Virginia; Benjamin Latrobe's Basilica of the Assumption in Baltimore; Mission San Miguel Arcangel in California (named to the National Trust for Historic Preservation's 11 Most Endangered Historic Places List, 2006), and the Hanging Flume in Colorado (named to the World Monuments Fund 2006 Watch List). He also conducts forensic investigations on wood-related failures, such as the collapse of Pavilion I at the University of Virginia. Additionally, he has participated in the development of standards and specifications for structural applications of wood, including the development of stress-grading procedures for lumber in the Philippines. Mr. Anthony is the 2002 recipient of the James Marston Fitch Foundation Grant for his approach to evaluating wood in historic buildings.

His activities extend to organizing and participating in workshops and lecturing on wood properties and the use of wood in construction applications. He has lectured at Columbia University, the University of Pennsylvania, Oregon State University, the University of Colorado and Colorado State University on investigating wood in historic buildings and given presentations at the Association for Preservation Technology International, Colorado Preservation, Inc., American Society of Civil Engineers conferences, and ICOMOS and RILEM symposia. He has authored approximately 80 publications; participated in conferences and seminars; and consulted throughout North America, Europe, Asia, Africa, Australia and the South Pacific. He is a member of the Association for Preservation Technology International, Colorado Preservation, Inc., the Society of Wood Science and Technology, RILEM, ICOMOS, the Forest Products Society and chairs the Committee on Forensic Investigation for the American Society of Civil Engineers.

BREAKOUT SESSIONS AND LIST OF PARTICIPANTS

BREAKOUT SESSION #1, WEDNESDAY, APRIL 23, 2008, 10:20 AM - 11:50 AM -- REGENCY C & D

Discussion Group #1	Discussion Group #2	Discussion Group #3	Discussion Group #4	Discussion Group #5	Discussion Group #6	Discussion Group #7	Discussion Group #8
"Green Buildings"	**"Hazard Mitigation"**	**"Advanced Materials"**	**"Performance of Wood Structures"**	**"Innovative Systems"**	**"Durability"**	**"Education and Technology Transfer**	**"Maintenance and Rehabilitation**
Facilitator: Tom Williamson	**Facilitator: John van de Lindt**	**Facilitator: Michael Wolcott**	**Facilitator: Dan Dolan**	**Facilitator: Erol Karacabeyli**	**Facilitator: Rakesh Gupta**	**Facilitator: Steve Cramer**	**Facilitator: Ron Anthony**
Scribe: Ben Herzog	**Scribe: Shiling Pei**	**Scribe: Lech Muszynski**	**Scribe: Vikram Yadama**	**Scribe: Mohammad Mohammad**	**Scribe: Aaron Kjeld**	**Scribe: Cathy Kaake**	**Scribe: Sam Zelinka**
Participants:	***Participants:***	***Participants:***	***Participants:***	***Participants:***	***Participants:***	***Participants:***	***Participants:***
Tim Allison	*Bill Bulleit*	*Don Bender*	*Marvin Criswell*	*Ghasan Doudak*	*Richard Desjardins*	*Peggi Clouston*	*Paul Crovella*
Carol Clausen	*Keyvan Karimifard*	*Kevin Cheung*	*Jim Groenier*	*Marjan Popovski*	*Karen Martinson*	*Lin Hu*	*RongFeng Huang*
Ken Fridley	*Yue Li*	*VJ Gopu*	*Jim Johnson*	*Phil Vacca*	*Matthew Reid*	*David Matousek*	*Wei Li*
Paul Jaehrlich	*Jennifer O*	*Dave Gromala*	*Minghao Li*	*Ned Waltz*	*Surendrakumar Shah*	*Mike Roberts*	*Chun Ni*
Ed Lim	*Weichiang Pang*	*Meho Karalic*	*Ciprian Pirvu*	*Phil Westover*	*Xiaobin Song*	*Mike Ritter*	*Andrea Surovek*
Doug Rammer	*Steve Pryor*	*Larry Stevig*	*Dave Prevatt*	*Ray Yu*	*James Wacker*	*Dan Wheat*	*Tom Tannert*
Ken Skog	*BJ Yeh*	*Richard Visscher*	*Dave Rosowsky*		*Jerry Winandy*		
			Bob Tichy				

BREAKOUT SESSION #2, WEDNESDAY, APRIL 23, 2008, 1:00 PM - 2:30 PM -- REGENCY C & D

Discussion Group #9	Discussion Group #10	Discussion Group #11	Discussion Group #12	Discussion Group #13	Discussion Group #14	Discussion Group #15	Discussion Group #16
"Green Buildings"	**"Hazard Mitigation"**	**"Advanced Materials"**	**"Performance of Wood Structures"**	**"Innovative Systems"**	**"Durability"**	**"Education and Technology Transfer**	**"Maintenance and Rehabilitation**
Facilitator: Tom Williamson	**Facilitator: John van de Lindt**	**Facilitator: Michael Wolcott**	**Facilitator: Dan Dolan**	**Facilitator: Erol Karacabeyli**	**Facilitator: Rakesh Gupta**	**Facilitator: Steve Cramer**	**Facilitator: Ron Anthony**
Scribe: Ben Herzog	**Scribe: Shiling Pei**	**Scribe: Lech Muszynski**	**Scribe: Vikram Yadama**	**Scribe: Richard Desjardins**	**Scribe: Aaron Kjeld**	**Scribe: Cathy Kaake**	**Scribe: Sam Zelinka**
Participants:	***Participants:***	***Participants:***	***Participants:***	***Participants:***	***Participants:***	***Participants:***	***Participants:***
Don Bender	*Marvin Criswell*	*Lin Hu*	*Ghasan Doudak*	*Bill Bulleit*	*Tim Allison*	*Paul Crovella*	*Paul Jaehrlich*
Peggi Clouston	*Ken Fridley*	*Yue Li*	*RongFeng Huang*	*Kevin Cheung*	*Carol Clausen*	*VJ Gopu*	*Ed Lim*
Dave Gromala	*Meho Karalic*	*Dave Prevatt*	*Weichiang Pang*	*Mohammad Mohammad*	*Wei Li*	*Jim Groenier*	*Karen Martinson*
James Johnson	*Minghao Li*	*Ken Skog*	*Mike Ritter*	*Ciprian Pirvu*	*Dave Matousek*	*Chun Ni*	*Steve Pryor*
Keyvan Karimifard	*Marjan Popovski*	*Ned Waltz*	*Tom Tannert*	*Mike Roberts*	*Xiaobin Song*	*Jennifer O*	*Mat Reid*
Surendrakumar Shah	*Dave Rosowsky*	*Ray Yu*	*Phil Vacca*	*Larry Stevig*	*Rick Visscher*	*Doug Rammer*	*Jim Wacker*
Jerry Winandy	*Andrea Surovek*	*BJ Yeh*	*Dan Wheat*	*Bob Tichy*	*Phil Westover*		

BREAKOUT SESSION #3, WEDNESDAY, APRIL 23, 2008, 3:00 PM - 4:30 PM -- REGENCY C & D

Discussion Group #17	Discussion Group #18	Discussion Group #19	Discussion Group #20	Discussion Group #21	Discussion Group #22	Discussion Group #23	Discussion Group #24
"Green Buildings"	**"Hazard Mitigation"**	**"Advanced Materials"**	**"Performance of Wood Structures"**	**"Innovative Systems"**	**"Durability"**	**"Education and Technology Transfer**	**"Maintenance and Rehabilitation**
Facilitator: Tom Williamson	**Facilitator: John van de Lindt**	**Facilitator: Michael Wolcott**	**Facilitator: Dan Dolan**	**Facilitator: Erol Karacabeyli**	**Facilitator: Rakesh Gupta**	**Facilitator: Steve Cramer**	**Facilitator: Ron Anthony**
Scribe: Ben Herzog	**Scribe: Shiling Pei**	**Scribe: Lech Muszynski**	**Scribe: Vikram Yadama**	**Scribe: Mohammad Mohammad**	**Scribe: Aaron Kjeld**	**Scribe: Cathy Kaake**	**Scribe: Sam Zelinka**
Participants:	***Participants:***	***Participants:***	***Participants:***	***Participants:***	***Participants:***	***Participants:***	***Participants:***
Kevin Cheung	*Paul Crovella*	*Bill Bulleit*	*Tim Allison*	*Marvin Criswell*	*RongFeng Huang*	*Ghasan Doudak*	*Don Bender*
Richard Desjardins	*VJ Gopu*	*James Johnson*	*Carol Clausen*	*Meho Karalic*	*Paul Jaehrlich*	*Ken Fridley*	*Jim Groenier*
Lin Hu	*Chun Ni*	*Ciprian Pirvu*	*Peggi Clouston*	*Yue Li*	*Ed Lim*	*Wei Li*	*Keyvan Karimifard*
Karen Martinson	*Dave Prevatt*	*Dave Rosowsky*	*Dave Gromala*	*Weichiang Pang*	*Doug Rammer*	*Steve Pryor*	*Minghao Li*
Dave Matousek	*Larry Stevig*	*Ken Skog*	*Mike Roberts*	*Rick Visscher*	*Mike Ritter*	*Mat Reid*	*Marjan Popvski*
Jennifer O	*Dan Wheat*	*Phil Vacca*	*Andrea Surovek*	*BJ Yeh*	*Ned Waltz*	*Surendra Kumar Shah*	*Xiaobin Song*
Bob Tichy		*Jerry Winandy*	*Jim Wacker*			*Tom Tannert*	*Phil Westover*
			Ray Yu				

List of Participants

Name	Affiliation
Allison, Timothy	Weyerhaeuser
Anthony, Ron	Anthony & Associates Inc.
Bender, Donald	Wood Materials & Enr Lab
Bulleit, William	Michigan Tech Univ.
Cheung, Kevin C	Western Wood Products Association
Clausen, Carol	USDA, FS, Forest Products Lab.
Clouston, Peggi	Massachusetts University
Cramer, Steven	Univ Of Wisconsin
Criswell, Marvin	Colorado State Univ
Crovella, Paul	SUNY-ESF, Syracuse
de la Roche, Ian	FP Innovations
Desjardins, Richard	FP Innovations-Forintek
Dolan, James	Washington State University
Doudak, Ghasan	The Canadian Wood Council
Fridley, Kenneth	The University of Alabama
Gagnon, Sylvain	
Gopu, Vijaya K	Tulane U.
Groenier, James	US Forest Service
Gromala, David	Weyerhaeuser
Gupta, Rakesh	Oregon State University
Herzog, Ben	Apa- The Eng. Wood Assoc.
Hu, Lin	
Huang, RongFeng	EPCOR Generation
Jaehrlich, Paul	
Johnson, James	Prairie Company Inc
Kaake, Catherine	SFPA
Karacabeyli, Erol	Forintek Canada Corp
Karalic, Meho	
Karimifard, Keyvan	
Kjeld, Aaron	APA - Eng. Wood Assoc
Li, Minghao	UBC
Li, Wei	Univ. of British Columbia
Li, Yue	Michigan Tech.
Lim, Ed	
Martinson, Karen	USDA Forests Products Lab.
Matousek, David	
Mohammad, Mohammad	FP Innovations
Muszynski, Lech	Oregon State Univ.
Ni, Chun	Forintek Canada Corp
O, Jennifer	FPInnovations-Forintek
Pang, Weichiang	Clemson
Pei, Shiling	Colorado St Univ.
Pirvu, Ciprian	Forintec Canada Corp
Popovski, Marjan	FPInnovations Forintek
Prevatt, David	Univ. of Florida
Pryor, Steven	Simpson Strong-Tie

Rammer, Douglas	USDA Forest Products Lab
Reid, Matthew	Blackwell Bowick Partnership
Ritter, Mike	US Forest Product Lab.
Roberts, Michael	
Rosowsky, David	Texas A&M University
Shah, Surendrakumar	Burk-Kleinpeter, Inc
Skog, Ken	USDA Forest Service
Song, Xiaobin	Forestry Science Ctr
Stevig, Larry	
Surovek, Andrea	
Tannert, Thomas	
Tichy, Robert	Washington State Univ.
Vacca, Philip	Louisiana-Pacific Corp.
Van De Lindt, John	Colorado State University
Visscher P.Eng., Richard	
WACKER, JAMES	USDA FS FPL
Waltz, Miles	Weyerhaeuser
Westover, Philip	Simpson Gumpertz & Heger Inc.
Wheat, Dan	UT - Austin
Williamson, Tom	APA - Eng. Wood Assoc.
Winandy, Jerrold	USDA Forest Service
Wolcott, Michael	Washington State Univ.
Yadama, Vikram	Washington St. Univ.
Yeh, Borjen	Apa-The Engineered Wood Association
Yu, Ray	Hardy Frames, Inc.
Zelinka, Samuel	USDA Forest Products Lab

AUTHOR INDEX

SUBJECT INDEX