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Current trends in USA building research

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Abstract
This publication provides an overview of the current trends in building research in the United States. The goal of the publication is to provide VTT personnel and Finnish industry with background information when assessing the opportunities for collaborative international research. The strengths and weaknesses of American R&D are noted, followed by information regarding the changing structure of research. Key building research topics were identified through review of the top engineering and architecture schools, as well as review of industrial building associations and companies. The final section of this publication provides some examples of future research directions, as identified from U.S. funding sources and independent organizations. Many appendices are included as a source of further internet information.

Keywords
R&D, research and development, building research, USA, trends, building, construction, information exchange, CAD, project management

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Contents

1. Introduction

Finland and VTT are striving to increase international cooperation. The opportunities for international partnerships and cooperative research are never-ending. To improve these opportunities, it is essential to have a good understanding of the market needs and future trends. One major market is the United States, where there are literary thousands of universities, associations and private companies involved in progressive R&D work.

Within the building sector, the general feeling among Finnish researchers seems to be that local Finnish practice is ahead of the U.S. technology development and implementation. A few of the key strengths of both markets are listed below. It should be noted that these are only the general impressions and not based on any proven statistics.

Strengths of U.S. research

- Greater experience in very large-scale design, construction and maintenance (such as nuclear facilities, dams, metros, skyscrapers, etc.).
- Strong work and education in topics related to construction project management, use of 4D-CAD to combine scheduling with design, energy conservation planning.
- Advanced in robotics and applied electronics, such as using data tags (i.e. within building automation).
- Advanced use of technology information exchange (due to large market). Use of subscription-based knowledge dissemination, data mining, ASP, project management sharing and scheduling. Project management tools can include social sciences inputs, such as personal behavior/choices.
- Ease for commercialization of ideas. Entrepreneurs encourage and possibly less fear of financial risks of failure.
- Ease of obtaining financing for large scale research (millions of dollars), based on reputation. Less bureaucracy.

Strengths of Finnish research

- Smaller market where it is easier to implement R&D results. Not as many competitors for technology development (funding).
- Lower turn-over or movement of researchers/key people due to small market (leads to consistency of R&D, which can be good or bad).
- Strong cross-border cooperation, also between industry and research.
- Use of more advanced construction technologies.
- Advanced in the field of building information modeling (BIM) and integrated simulations, with established standards and implementation record.

- Better design for indoor climate (i.e. energy use for heating, insulated windows, lack of full carpeting, etc.).
- Emphasis in Finnish culture and practice on environmental issues and energy conservation.
- Greater understanding and acceptance of considering whole life cycle during construction/use.

This publication addresses the current trends in U.S. building research and aims at providing Finnish industry with background information when assessing the opportunities for collaborative international research. Key building research topics were identified through review of current web pages of the top engineering and architecture schools, as well as review of industrial building associations and companies. The following section also notes how the structure of research is changing.

2. Direction of research structure

Many universities in the U.S.A. appear to be addressing the need for 'cross-discipline' research. Some universities have started to or have already re-structured their departments to promote greater scientific break-through by cooperation. Stanford University's School of Engineering (Appendix A) had a good summary of this idea when saying: "Many of the greatest innovations of the past were driven by collaborations that reached across traditional boundaries. We believe that the most promising opportunities for discovery still exist at the intersections of disciplines, and that the technologies of the next century will grow out of interdisciplinary partnerships."

To achieve these goals, Stanford has also established a "Collaboratory for Research on Global Projects" (CRGP) to equip leaders in government and industry with models, tools and strategies to improve the outcomes of large, complex, global projects. Within CRGP, once group is the "Center for Integrated Facility Engineering" (CIFE) for developing theory, methodology and tools to optimize the design of project organizations. CIFE allocates industrial funding from its partners to research projects on the following topics:

- visualization
- product and process modelling
- internet collaboration
- facilities management
- supply chain management and E-commerce
- management of technology
- education.

VTT and Finnish universities are active members and participant in the CRGP and CIFE programs. More details about the program activities can be found at http://crgp.stanford.edu/ and http://cife.stanford.edu/.

The Massachusetts Institute of Technology (MIT) (Appendix A) has wonderful examples of how they have re-structured their teaching and research to facilitate interdisciplinary partnerships. The university does not function across traditional roles of independent colleges or schools (such as architecture or engineering branches). Some examples of how their programs are now structured include the following:

- 'Building Technology Program', jointly sponsored by the Departments of Architecture, Civil and Environmental Engineering, and Mechanical Engineering: http://web.mit.edu/bt/www/. The program addresses materials, manufacturing and thermo-fluid sciences for construction of new buildings, retrofit or rehabitation of existing buildings and the efficient operation of buildings.

- ‘Digital Design Fabrication Group’, for education and research in areas of rapid prototyping and CAD/CAM fabrication for architects and designers: http://ddf.mit.edu/.
- ‘Nanotechnology Groups’ (including for instance NanoEngineering Group, NanoMechanical Technology Laboratory and NanoStructures Laboratory). A lot of research news about this group is published at http://web.mit.edu/newsoffice/topic/nanotech.html.

Parallel to the restructuring of university systems, the primary funding organization for science and engineering research in the U.S., the National Science Foundation (NSF), has also been involved in restructuring lately. NSF plans to implement a major reorganization of their Directorate for Engineering, to improve multidisciplinary work and better address emerging challenges and frontier ideas. (Reppert 2006.)

NSF also recently released their 5-year strategic plan (National Science Foundation 2006) and their investment priorities include the following issues among others:

- promoting multidisciplinary research
- investigating social dimensions of new technology, including safety
- fostering research improving sustainability on Earth
- advancing fundamental research to drive discovery, especially with regards to cyberinfrastructure and networking
- strengthening and developing new collaborations through innovative partnerships to leverage intellectual capabilities, both nationally and internationally.

NSF has an Office of International Science and Engineering (OISE, http://www.nsf.gov/div/index.jsp?div=OISE), to promote international cooperation. This office has also recently restructured its programs to improve how it provides international research and education experiences for U.S. students and junior researchers. The goal of the OISE activities is to build a more inclusive and globally-engaged workforce that fully reflects the strength of our diverse population. In some cases, VTT would be eligible for specific grants, such as program specific grants to foster cooperation on a specific topic (i.e. a current grant is listed for U.S. German cooperation in Chemical Engineering). There is also the NSF on-going International Research Fellowship Program (IRFP) grant to introduce scientists and engineers in the early stages of their careers to international collaborative research opportunities, which could include visiting researchers coming to Finland.

In the past few years, engineering colleges and departments around the U.S. have seen a surge in applicants. *U.S. News* magazine (Kingsbury 2005) reports that graduate degrees are in high-demand and graduates are receiving multiple job offers and high salary offers. The article describes some of the booming fields, including nanotechnology, based mostly on data from the U.S. Department of Labor. They report that the key engineering fields, such as environmental and biomedical, are expecting employment growth up to 27% through the year 2014. Nearly all fields will see growth, such as civil and chemical engineering each seeing 17% growth.

3. Key research topics

3.1 Overview

Regarding specific basic research areas in the U.S., the main topics that are presented as the current, prominent R&D areas are quite similar when investigating various sources. The same 'key terms' are seen repeatedly as areas for focusing funding and resources. The primary sources for information on basic research were the top engineering departments of U.S. universities, as listed by *U.S. News* magazine's annual report (see listing in Appendix A). The top architecture schools (as listed in Appendices B and C) in the U.S. were also examined, and some input from their web pages is also included here.

The School of Engineering at Stanford University (Appendix A) presents a good summary of these key research topics within their Strategic Initiatives. "To guide Stanford's growth, their dean has identified four major areas for long-term investment:

- Information Technology: Hardware, software and communications are the pillars of information technology. Continuing research in these fields ranges from basic science, through materials and devices, to systems and applications.
- Bioengineering/Health: A fusion of engineering and the life sciences promises new discoveries, technologies, and therapies to improve human health and the environment.
- Environment and Energy: Meeting the needs of a growing world population in an environmentally sustainable way is a major challenge of the 21st century.
- Nanoscience and Nanotechnology: Advancing the science and technology of very small structures holds vast opportunities for research and application development."

Many schools, such as Georgia Institute of Technology, also listed research initiatives on the topic of Security. Regarding architecture topics, there appears to be a lot of emphasis placed on digital design and Building Information Modelling (BIM). Many of the key R&D results from the building sector are directly applied by real estate owners in the U.S.A. For instance, the U.S. General Services Administration (GSA) has a lot of interest in the building information modeling (BIM) and tools in which VTT is actively developing through international partnerships associations.

These six key topics listed above were typically seen within the descriptions of focus research areas for most science schools in the U.S. For instance, all of the top 10 engineering schools, including MIT, Berkeley, Purdue and Cornell, had established a nanotechnology center or considered themselves a global leader in nanoscale science and engineering. The Berkeley Nanoscience and Nanoengineering Institute http://nano.berkeley.edu/nanosite/ appears to be one of the most comprehensive.

As an example of some of the key research areas, Purdue University's Nanotechnology Center lists the following possibilities for profound nanotechnology influences in the 21st century (Appendix A):

- The creation of new materials with superior strength, electrical conductivity, resistance to heat and other properties.
- Microscopic machines for a variety of uses, including probes that could be injected into the body for medical diagnostics and repair.
- A technology in which biology and electronics are merged, creating "bio-chips" that detect food-borne contamination, dangerous substances in the blood or chemical warfare agents in the air.
- The creation of artificial organs and prosthetics that enhance the quality of life.
- The development of "molecular electronics" and devices that "self assemble," similar to the growth of complex organic structures in living organisms. Theoretically, such self-assembling devices could make electronics processing far less expensive than conventional semiconductor processing.

The importance of a coordinated U.S. Federal program for nanotechnology R&D was given greater recognition in 2003 with the enactment of the 21st Century Nanotechnology Research and Development Act (Public Law 108-153). The 2007 U.S. government's budget provides over $1.2 billion for the multi-agency National Nanotechnology Initiative (NNI), bringing the total investment since the NNI was established in 2001 to over $6.5 billion and nearly tripling the annual investment of the first year of the Initiative. This sustained investment aims at advancing understanding of the unique phenomena and processes that occur at the nanometer scale and expedites the responsible use of this knowledge to achieve advances in medicine, manufacturing, high-performance materials, information technology, and energy and environmental technologies.

The National Science Foundation (NSF) is the lead federal agency providing NNI support through funding of efforts in fundamental nanoscale science and engineering, as well as research to understand the likely impacts of nanotechnology on society.

3.2 University specific topics

Many of the top universities (see Appendices A–C) in both architecture and engineering have identified their focus areas. An abbreviated listing of some of these university-specific topics is provided here, along with their internet links for further information.

Cornell University, Department of Engineering, strategic areas of significant research focus:

- Systems Biology and Biomedical Engineering
- Nanomaterials, Nanodevices. and Nanoscience
- Energy, Environment, and Sustainable Development
- Information, Computation, and Communication
- Advanced Materials
- Complex Systems and Networks

http://www.engineering.cornell.edu/research/strategic-areas/index.cfm

Georgia Institute of Technology, College of Engineering, current prominent research initiatives underway:

- Energy
- Environment
- Health (Cancer, Health Systems, Predictive Health)
- Security

http://www.coe.gatech.edu/research/initiatives.php

College of Architecture, has the following centers:

- Advanced Wood Products Laboratory
- Center for Assistive Technology and Environmental Access
- Center for Geographic Information Systems
- Center for Quality Growth & Regional Development
- Construction Resource Center
- Interactive Media Architecture Group IN Education

http://www.coa.gatech.edu/

Harvard University, Graduate School of Design (Architecture), http://www.gsd.harvard.edu/research/ list 5 research centers:

- Joint Center for Housing Studies
- Public Housing Operational Cost Study
- Real Estate
- Center for Technology & the Environment
- The Aga Khan Program for Islamic Architecture

Lawrence Berkeley National Laboratory http://www.lbl.gov/

Berkeley Lab has done science and engineering research for more than 70 years, holding the distinction of being the oldest of the U.S. Department of Energy's National Laboratories. The Lab is managed by the University of California, operating with an annual budget of more than $500 million (FY2004) and a staff of about 3,800 employees, including more than 500 students. Berkeley Lab conducts unclassified research across a wide range of scientific disciplines with key efforts in fundamental studies of the universe; quantitative biology; nanoscience; new energy systems and environmental solutions; and the use of integrated computing as a tool for discovery. Contact (guest researcher at VTT 2006): Vladimir Bazjanac, Building Technologies, Lawrence Berkeley National Laboratory, +1 510 486 4092, e-mail: V_Bazjanac@lbl.gov.

Massachusetts Institute of Technology http://www.mit.edu
Heavy emphasis put on research participation by students. For instance, in the building technology program, the following topics are listed (all of which include their own sub-topics and internet links):

- Building Ventilation and Diagnostics
- Building Energy Studies
- Building Materials and Construction
- Evaluation of Sustainable Options
- Daylighting
- Structures
- Computer Graphics for Physical Performance
- Indoor Air Quality, Building Ventilation, and Building Environment Modeling
- Sustainable Building Design

Purdue University, College of Engineering, Research Signature Areas (est. 2003):

- Advanced Materials and Manufacturing
- Energy
- Global Sustainable Industrial Systems
- Healthcare Engineering
- Information, Communications and Perception Technologies
- Intelligent Infrastructure Systems
- Nanotechnologies and Nanophotonics
- System of Systems
- Tissue and Cellular Engineering

https://engineering.purdue.edu/Engr/Research/Initiatives/

Stanford University, School of Engineering research initiatives:

- Information Technology
  Bioengineering/Health
- Environment and Energy
- Nanoscience and Nanotechnology

http://soe.stanford.edu/initiatives/index.html

Collaboratory for Research on Global Projects (CRGP) http://crgp.stanford.edu/
Center for Integrated Facility Engineering (CIFE) http://cife.stanford.edu/

University of California – Berkeley, College of Engineering
http://www.coe.berkeley.edu/

University of Illinois-Urbana-Champaign, College of Engineering, major research laboratories:

- Advanced Transportation Research and Engineering Laboratory (ATREL)
- Coordinated Science Laboratory (CSL)
- Micro and Nanotechnology Laboratory (MNTL)
- Frederick Seitz Materials Research Laboratory (MRL)

http://www.engr.uiuc.edu/

University of Michigan, School of Architecture and Urban Planning
http://www.tcaup.umich.edu/arch/

University of Pennsylvania, School of Design http://www.design.upenn.edu/index.php

University of Texas at Austin, School of Architecture http://soa.utexas.edu/
UTexas also has a 'Center for Sustainable Development' http://www.utcsd.org/

Yale University, School of Architecture http://www.architecture.yale.edu

4. Future scientific direction

To gain a better understanding of what topics will be emerging in technologies, a review of funding organizations was done. By examining what types of projects and open calls are available, it was possible to gain an overview of what industry and society needs are being addressed. Some of the main locations for obtaining information are summarized in Chapter 5 and Appendix D, with key information regarding R&D in the building sector provided in the following sections.

The National Science Foundation (NSF) has 12 key areas, which include earth/environment, engineering as well as nanoscience. In 2003, the Engineering Directorate alone provided $450 million in support for research and education activities. The Engineering Directorate lists a few examples of new areas for technology and scientific discovery:

- novel medical treatments, including new antibiotics
- new sensors and sensor networks to enhance homeland security
- new tools and methods to enhance the structural integrity of buildings and infrastructure
- new technologies to enable ultrafast computers and ultra-small nanoscale manufacturing.

In 2006, the U.S. Government passed the American Competitiveness Initiative (ACI) (ACI 2006). The ACI includes a commitment to double investment over 10 years in key Federal agencies – including the National Science Foundation (NSF) – that support basic research in the physical sciences and engineering. The ACI commits $5.9 billion in 2007 to increase investments in R&D, strengthen education and encourage entrepreneurship.

The National Research Council (NRC) is part of the U.S. National Academies and funds science, technology and health research. Currently there are 372 projects underway at NRC in all disciplines, including over 100 in the Division of Engineering. Some examples of current Engineering project related to building technology include the following:

- Sustainable Underground Storage of Recoverable Water
- Core Competencies for Federal Facilities Asset Management, 2005–2020
- Review and Assessment of the Health and Productivity Benefits of Green Schools
- Assessing the Impacts of Changes in the Information Technology Research and Development Ecosystem
- Using Information Technology to Enhance Disaster Management
- Assessment of Security Technologies for Transportation
- Review of the National Nanotechnology Program.

In 2002 the Continental Automated Buildings Association (CABA) released a 66-page Technology Roadmap (TRM) for Intelligent Building Technologies (CABA 2002). This report was the result of a collaborative research project between industry and five federal Canadian government departments and agencies. The project focused upon commercial, institutional and high-rise residential buildings, and culminated in a final report that provides an in-depth examination of intelligent buildings technologies. The TRM concluded as follows:

> *There are a significant number of intelligent building technologies products currently on the market capable of automating and integrating all major systems, but the degree of their implementation throughout the marketplace is inadequate largely because of a lack of knowledge and understanding about the systems. The report recommends that the industry should increase awareness of the benefits of intelligent building technology to stimulate research and development. A key recommendation is for industry to develop instrumented reference examples and demonstration projects to place emphasis on the benefits of intelligent building technologies. Such measurements will allow industry to quantify cost-savings and energy efficiencies from the deployment of such technologies.*

The TRM report also listed the following current trends in intelligent building technologies:

- to integrate communications, providing an overall or umbrella integration solution
- to ensure that the existing systems are capable of operating independently, i.e., standalone
- to move toward a single software front end which communicates with a single console
- to gradually phase out separate control rooms for different functions
- to change from project development based on lowest initial cost to development based on highest value, correctly reflecting higher revenues and operational costs savings
- to encourage suppliers to develop intelligent, self/diagnosing, fault tolerant controllers.

The Rand Corporation is a nonprofit institution providing research and analysis on a variety of topics. They have 15 core research areas, including: 1) energy and environment, 2) science and technology, 3) transportation and infrastructure. They list 22 ‘hot topic’ areas of research, which include: 1) Climate change, 2) Energy, and 3) Privacy, Security, and Electronic Surveillance. Some examples of research projects and publications that are linked to the building sector include the following:

- Greater Effort Needed to Reduce Health Risks Posed by Nanomaterials
- Protecting Emergency Responders at Large Building Collapses
- Measures of Residential Energy Consumption and Their Relationships to DOE Policy
- Regional Differences Affect the Price and Demand for Energy
- A Sequential-Decision Strategy for Abating Climate Change
- The Environmental Implications of Population Dynamics
- Asbestos-Related Claims Exceed 730,000, Cost More than $70 Billion.

5. Prominent research organizations, companies and associations

When compiling the information in this publication, a wide range of internet-based literature was reviewed for the prominent research organizations, companies and associations from the U.S. building sector. A short summary of these different key players are give here, along with their internet links for further information.

American Concrete Institute (ACI) http://www.concrete.org
ACI aims to develop, share, and disseminate the knowledge and information needed to utilize concrete to its fullest potential. They have a wealth of committees, provide hundreds of educational activities each year, and are active in supporting industry cooperation.

American Forest and Paper Association (AF&PA) http://www.afandpa.org/
AF&PA is a newly combined organization of the National Forest Products Association (NFPA) and the American Paper Institute (API). It represents forest and building products industries, as well as pulp, paper, and paperboard manufacturers. It is the leading voice for the forest products industry at the state, national, and international level. AF&PA provides education and is active in campaigning for many policy issues, including international competitiveness, environment, energy, recycling and green building. They note key topics for economical and social benefits to include better energy and water efficiency, reduced solid waste output and conservation of natural resources.

American Institute of Architects (AIA) http://www.aia.org/
AIA works to create more valuable, healthy, secure, and sustainable buildings and cityscapes. They provide education/training and are active in government advocacy. They have 26 'Knowledge Communities' where their members pursue key topics as well as facilitate the generation and exchange of knowledge. Some of these include: 1) Center for Building Science and Performance (CBSP), 2) Environment/Sustainability, 3) Committee of Corporate Architects and Facility Management (CAFM).

American Institute of Steel Construction (AISC) http://www.aisc.org/
AISC is a technical institute and trade association, serving the U.S. structural steel design community and construction industry. AISC's mission is to make structural steel the material of choice by being the leader in structural-steel-related technical and market-building activities, including: specification and code development, research, education, technical assistance, quality certification, standardization, and market development.

Construction Industry Institute (CII) http://www.construction-institute.org
CII is a consortium of leading owners, engineering and construction contractors, and suppliers with the mission of improving the cost effectiveness of the capital facility project life cycle. CII does research, implementation, and education. The consortium funds research programs in the engineering and construction industry, involving more than 30 leading U.S. universities.

Continental Automated Buildings Association (CABA) http://www.caba.org
CABA is an industry association that promotes advanced technologies for the automation of homes and buildings in North America. They are dedicated to providing information, education and networking opportunities relating to home and building automation. They have a research library, accessible to members. Library includes promoting resources that enable one to identify products, technologies and industry trends. In 2002 they published a 66-page "Technology Roadmap for Intelligent Buildings". VTT is a member (our contact is Pekka Pajakkala).

Federal Highway Administration (FHWA) http://www.fhwa.dot.gov
FHWA is a part of the U.S. Department of Transportation (DOT) and is responsible of ensuring that America's roads and highways continue to be the safest and most technologically up-to-date. They have an office of research and development (http://www.fhwa.dot.gov/orgrdat.htm) and their own Turner-Fairbank Highway Research Center. Their main research areas include

- Human Centered Systems
- Materials Technology
- Operations & Intelligent Transportation Systems (ITS)
- Pavements
- Safety
- Structures.

FIATECH http://www.fiatech.org
This non-profit consortium is comprised of vendor companies, owner/operators, engineering firms, and construction companies, who are able to pool resources and talent and focus them on critical technology issues and innovations in the capital construction process. They are focused on fast-track development and deployment of technologies to substantially improve how capital projects and facilities are designed, engineered, built and maintained. They pool resources to conduct R&D work, and some examples of recent projects are

- Life Cycle Data Management
- Value Streamlining Control Valve Engineering and Procurement
- Valuing Emerging Technologies (including VTT work by A. Kiviniemi)
- Leveraging Technology to Improve Construction Productivity.

Frost & Sullivan http://www.frost.com
This private company has 26 global offices with more than 1500 industry consultants, market analysts, technology analysts and economists. Their mission is to research and analyze new market opportunities for corporate growth. Their integrated areas are technology research, market research, economic research, corporate best practices, training, customer research, competitive intelligence and corporate strategy. Their Building Technologies division focuses on the key areas of HVAC&R, Fire & Life Safety, Building Automation Systems (BAS), Lighting Controls & Products, Performance Contracting, Facility Management (I-FM) Services, Security Controls, and Home Automation. They also have supplementary programs in Water & Wastewater, Environmental Management, Waste Management, and Environmental Health & Safety.

General Services Administration (GSA) http://www.gsa.gov
GSA is the U.S. government's "landlord", meeting office and other space requirements of the federal workforce. GSA is also the premier federal acquisition and procurement force offering equipment, supplies, telecommunications, and integrated information technology solutions to customer agencies. GSA also plays a key role in developing and implementing policies that affect many government agencies and helps other federal agencies improve their service to and communication with the public by offering effective citizen-response tools and services. GSA has 10 regional offices around the U.S., with 13,000 employees. GSA acts as a catalyst for nearly $66 billion in federal spending – more than one-fourth of the government's total procurement dollars. The agency also influences the management of federal assets valued at nearly $500 billion. These assets include more than 8,300 government-owned or leased buildings, an interagency fleet of 170,000 vehicles, and technology programs and products ranging from laptop computers to systems that cost over $100 million.

International Alliance For Interoperability (IAI) http://www.iai-na.org/
IAI is a global standards-setting organization representing widely diverse constituencies – from architects and engineers, to research scientists, to commercial building owners and contractors, to government officials and academia, to facility managers, and to software companies and building product manufacturers. Their vision is to improve communication, productivity, delivery time, cost, and quality throughout the whole building life cycle. The IAI mission is to provide a universal basis for process improvement and information sharing in the construction and facilities management industries. Alliance members are committed to promoting effective means of exchanging information among all software platforms and applications by adopting a single Building Information Model (BIM). On of their highlighted industrial solutions is the "Pro IT" development project from VTT (June 2002 – December 2004), which was initiated by the Confederation of Finnish Construction Industries RT. The objective of

the project was to define a national data management approach and guidelines for the construction process, based on product modeling.

Institute of Electrical and Electronics Engineers (IEEE) http://www.ieee.org/portal/site
IEEE is a professional association for the advancement of technology, including areas ranging from aerospace systems, computers and telecommunications to biomedical engineering, electric power and consumer electronics.

Nanoscience and Technology Institute (NSTI) http://www.nsti.org
NSTI conducts and supports scientific and engineering research in disciplines ranging from chemistry and physics to information technology. In carrying out this research, NIST works collaboratively with colleagues in industry, academia, and government. NIST offers membership services, continuing education programs, scientific and business publishing and community outreach.

National Association of Home Builders (NAHB) http://www.nahb.org/
NAHB is a trade association focused on education and helping promote house building policies.

National Institute of Standards and Technology (NIST) http://www.nist.gov/
NIST works with industry to develop and apply technology, measurements, and standards. They are divided into 8 laboratories, one of which is the Building and Fire Research Laboratory (BFRL). BFRL focuses on building materials; computer-integrated construction practices; fire science and fire safety engineering; and structural, mechanical, and environmental engineering. Products of the laboratory's research include measurements and test methods, performance criteria, and technical data that support innovations by industry and are incorporated into building and fire standards and codes. Their key research areas are

- High Performance Construction Materials and Systems
- Fire Loss Reduction
- Enhanced Building Performance
- Homeland Security.

National Nanotechnology Initiative (NNI) http://www.nano.gov/
NNI invests in fundamental research to further understanding of nanoscale phenomena and facilitate technology transfer. The goals of NNI are

- maintain a world-class research and development program aimed at realizing the full potential of nanotechnology
- facilitate transfer of new technologies into products for economic growth, jobs, and other public benefit

- develop educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology
- support responsible development of nanotechnology.

The NNI budget is used or disseminated by the following U.S. agencies, some of whom are also described in this publication: NSF, DOD, DOE*, DHHS (NIH), DOC(NIST), NASA, EPA, USDA (CSREES), DHHS (NIOSH), USDA/FS, DOJ, DHS, DOT (FHWA).

National Precast Concrete Association (NPCA) http://www.precast.org
NPCA is a trade association providing education and technical services within the precast concrete products industry. They support manufacturers and companies that provide the equipment, supplies and services to make these products.

National Research Council (NRC) http://www.nationalacademies.org/nrc/
NRC is part of the National Academies, which also includes the National Academy of Sciences, National Academy of Engineering and Institute of Medicine. 85% of their funding comes from the government and their goal is to provide science, technology and health policy advice under a congressional charter.

National Science Foundation (NSF) http://www.nsf.gov/
NSF is an independent government agency responsible for promoting science and engineering through programs that invest over $3.3 billion per year in almost 20,000 research and education projects. Each year NSF oversees about 35,000 active awards across all disciplines in science and engineering. Merit review results in about 10,000 new awards each year from over 40,000 proposal submitted by the research and education community. The regional contact person at NSF for research in Finland is Mrs. Bonnie Thompson, e-mail: bhthomps@nsf.gov.

Portland Cement Association (PCA) http://www.cement.org/
PCA represents cement companies in the United States and Canada. It conducts market development, engineering, research, education, and public affairs programs. PCA currently has more than 70 research projects in its core program. The value of PCA's active projects (multi-year) is more than $7 million. PCA research dollars are matched equally by allied industry and government agencies. 11-page PDF file available summarizing 2006 projects.

Rand Corporation http://www.rand.org/about/
Rand is a nonprofit institution that helps improve policy and decision-making through research and analysis, with focus areas of business, education, health, law, national security and science. They have 15 core research areas, including: 1) energy and

environment, 2) science and technology, 3) transportation and infrastructure. They list 22 'hot topic' areas of research, which include: 1) Climate change, 2) Energy, and 3) Privacy, Security, and Electronic Surveillance. Some examples of recent research projects and publications that are linked to the building sector include

- Protecting Emergency Responders at Large Building Collapses
- Measures of Residential Energy Consumption and Their Relationships to DOE Policy
- A Sequential-Decision Strategy for Abating Climate Change
- The Environmental Implications of Population Dynamics
- Asbestos-Related Claims Exceed 730,000, Cost More than $70 Billion.

Transportation Research Board (TRB) http://www.trb.org/
TRB is part of the National Academies and aims to provide near-term, practical solutions to problems facing transportation agencies. Their annual budget is about $35 million for research studies, typically covering about 40 new projects per year.

U.S. Army Construction Engineering Research and Development Center (CERL)
http://www.cecer.army.mil/td/tips/index.cfm
Conducting research and development in infrastructure and environmental sustainment to develop new technologies that help military installations provide and maintain quality training lands and facilities. CERL's major research areas are the following:

- Facility Acquisition and Revitalization (includes Facility Delivery Process Improvement and Enduring Building Systems sub-areas)
- Installation Operation (includes Energy sub-area)
- Military Land Management (includes Ecosystem Management, Land Management, Land Restoration, Land Use Planning sub-areas).

6. Summary

The strategic development plan for VTT and Finnish building research has been established, and is in-line with Finnish and European Union focus areas. After review of the current state of R&D in the United States, it is evident that the VTT strategy is also in agreement with the key focus areas in the U.S. building sector. Similar topics to VTT's are highlighted by U.S. research organizations, such as nanotechnology, ICT, environment, safety and building information modeling. Finland and VTT research and technology implementation on many of these topics seems to be more advanced than in the U.S., due to the smaller Finnish market with a closer-knit industry who supports R&D. With proper marketing, the outlook for VTT's and Finland's future international cooperation should be promising due to our extensive experience and expertise.

7. Acknowledgements

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Appendix A: Top 50 engineering schools

"America's Best Graduate Schools 2007", *U.S. News and World Report,* 2006.
From: http://www.usnews.com/usnews/edu/grad/rankings/eng/brief/engrank_brief.php.

Top 50 engineering schools:

1. Massachusetts Institute of Technology
2. Stanford University (CA)
3. University of California–Berkeley
4. Georgia Institute of Technology
5. University of Illinois–Urbana-Champaign
6. Purdue University–West Lafayette (IN)
6. University of Michigan–Ann Arbor
8. Carnegie Mellon University (PA)
9. University of Southern California (Viterbi)
10. California Institute of Technology
11. Cornell University (NY)
11. University of California–San Diego (Jacobs)
13. University of Texas–Austin
14. Texas A&M University–College Station (Look)
15. University of California–Los Angeles (Samueli)
15. University of Maryland–College Park (Clark)
15. University of Wisconsin–Madison
18. Princeton University (NJ)
19. Pennsylvania State University–University Park
20. Columbia University (Fu Foundation) (NY)
21. Harvard University (MA)
21. Johns Hopkins University (Whiting) (MD)
21. Northwestern University (McCormick) (IL)
21. University of California–Santa Barbara
21. University of Washington
26. Ohio State University
26. University of Florida
28. University of Minnesota–Twin Cities
29. Rice University (Brown) (TX)
30. Duke University (NC)
30. Virginia Tech
32. University of Pennsylvania
33. North Carolina State University
33. Washington University in St. Louis (Sever)
35. University of California–Davis

35. University of Rochester (NY)
37. Rensselaer Polytechnic Institute (NY)
38. University of Virginia
39. University of Colorado–Boulder
39. Yale University (CT)
41. University of California–Irvine (Samueli)
42. Boston University
42. Case Western Reserve University (OH)
42. Dartmouth College (Thayer) (NH)
42. Iowa State University
42. University of Delaware
47. Arizona State University (Fulton)
47. Lehigh University (Rossin) (PA)
47. Rutgers State University–New Brunswick (NJ)
47. Vanderbilt University (TN)

Appendix B: Top architecture schools, list 1

"Practitioners' Rank Best Architecture Schools for 2003," *Design Intelligence*, Vol. 8, No. 2, 2002. From: http://www.di.net/.

Best Architecture Program Rankings

	03	02	01	00
Harvard University	1	2	2	2
Cal Poly, San Luis Obispo	2	—	—	—
University of Cincinnati	3	3	6	3
Cornell University	4	1	1	1
Yale University	5	10	3	6
University of Texas at Austin	6		10	
Kansas State University	6	–	–	10
University of Michigan	8	5	5	3
University of Pennsylvania	8	15	11	5
Columbia University	10	13	7	10
Rice University	10	–	4	–
Auburn University	10	–	–	–
U. of Illinois, Urbana-Champaign	14	8	–	12
Texas A&M University	14	10	15	–
Massachusetts Institute of Tech.	14	12	8	–
Ball State University	14	–	–	–
Virginia Tech.	14	–	–	–
Syracuse University	–	4	–	7
Georgia Institute of Technology	–	5	–	–
Iowa State University	–	7	–	–
University of Virginia	–	8	14	7
University of Notre Dame	–	14	–	13
University of California, Berkeley	–	–	9	–
Princeton University	–	–	11	13
Rhode Island School of Design	–	–	13	7
Pennsylvania State University	–	–	–	13

Appendix C: Top architecture schools, list 2

Stevens, Garry, "Ratings of the USA's best architecture schools", Center for Architectural Sociology, 2006. From: http://www.archsoc.com/kcas/researchschool4.html. The results are a ranking of over 100 U.S. architecture schools in terms of research performance after review of over 2000 architecture professors.

School	Research Intensity
Princeton University	25
Columbia University	25
Cooper Union for the Advancement of Science and Art, The*	22
Yale University	20
University of California, Los Angeles	18
Harvard University	17
University of Pennsylvania	17
Massachusetts Institute of Technology	14
Rice University	10
University of Notre Dame	10
Arizona State University	8
University of Illinois at Urbana-Champaign	8
University of California, Berkeley	8
University of Maryland	8
New Jersey Institute of Technology	8
University at Buffalo, SUNY	7
University of Texas at Austin	7
University of Virginia	6
University of Michigan	6
University of Minnesota	6
Southern California Institute of Architecture*	6
University of Wisconsin Milwaukee	6
Northeastern University	5
University of Washington	5
Georgia Institute of Technology	5
University of Illinois at Chicago	5
Cornell University	5
Rhode Island School of Design*	5
University of New Mexico	5
City College of New York, CUNY	5
University of Kansas	5
Pratt Institute	4

University of Cincinnati	4
University of Miami	4
University of Oregon	4
University of Southern California	4
University of Florida	4
Woodbury University	4
Washington University in St Louis	4
Miami University	4
Syracuse University	4
Texas A&M University	4
University of Texas at Arlington	3
Kansas State University	3
University of Tennessee, Knoxville	3
Ohio State University	3
University of Houston	3
Texas Tech University	3
Roger Williams University	3
North Carolina State University	3
Virginia Polytechnic Institute and State University	2
Louisiana State University	2
California College of the Arts	2
Carnegie Mellon University	2
University of Massachusetts Amherst	2
Iowa State University	2
Norwich University	2
University of Utah	2
University of Texas at San Antonio	2
Ball State University	2
Clemson University	2
Rensselaer Polytechnic Institute	2
Florida International University	2
Kent State University	2
Illinois Institute of Technology	2
California Polytechnic State University, San Luis Obispo	2
Catholic University of America	2
Drexel University	2
Morgan State University	2
New York Institute of Technology	2
University of Hawaii at Manoa	2
University of Kentucky	2
University of Nebraska – Lincoln	2

Appendix D: Other federal research laboratories & funding agencies

(from http://www.engr.uiuc.edu/research/agencies.php)

A collection of some laboratories and agencies that fund university research or support collaborations with researchers.

Defense Advanced Research Projects (DARPA) http://www.darpa.mil/
Manages basic and applied research and development projects for the Department of Defense.

Argonne National Laboratories (ANL) http://www.anl.gov/
A U.S. Department of Energy laboratory operated by the University of Chicago.

National Aeronautics & Space Administration
http://www.nasa.gov/externalflash/nasa_gen/index.html
Committed to aeronautics and space research.

U.S. Air Force Office of Scientific Research http://www.afosr.af.mil/
The research mission is to sponsor and sustain basic research, transfer and transition research results, and support Air Force goals of control and maximum utilization of air and space.

U.S. Army Research Office
http://www.arl.army.mil/main/main/default.cfm?Action=29&Page=29
The mission of this office is to seed scientific and far reaching technological discoveries that enhance Army capabilities.

U.S. Department of Energy (DOE) http://www.science.doe.gov/
Working to foster a secure and reliable energy system that is environmentally and economically sustainable, to be a responsible steward of the Nation's nuclear weapons, and to support continued U.S. leadership in science and technology.

U.S. Fedworld Home Page http://www.fedworld.gov/
A program of the U.S. Department of Commerce offering a comprehensive central access point for searching, locating, ordering and acquiring government and business information.

U.S. Office of Naval Research http://www.onr.navy.mil/
Coordinates, executes, and promotes the science and technology programs of the United States Navy and Marine Corps through universities, government laboratories, and nonprofit and for-profit organizations.

The White House http://www.whitehouse.gov/
News and information from the White House.

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