JOURNAL OF
CONSTRUCTION INNOVATION

CONSTRUCTION INNOVATION – AN ANNOTATED BIBLIOGRAPHY[1]

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Abstract: This annotated bibliography covers journal articles, conference proceedings, books, and dissertations on construction innovation and in some cases general industrial innovation. References to the most current Internet sites that promote and disseminate information about innovations in construction are included as a special section. The primary target was general literature on construction innovation management, methods, implementation, technology transfer, models, and history. Most articles that dealt with a particular construction innovation such as a new construction material or a new piece of construction equipment were not included. Some references describe manufacturing models and applications that can be used in construction.

INTRODUCTION

This annotated bibliography covers journal articles, conference proceedings, books, and dissertations on construction innovation and in some cases general industrial innovation. References to the most current Internet sites that promote and disseminate information about innovations in construction are also included as a special section. The primary target was general literature on construction innovation management, methods, implementation, technology transfer, models, and history. Most articles that dealt with a particular construction innovation such as a new construction material or a new piece of construction equipment were not included. Some references describe manufacturing models and applications that can be used in construction. The earliest reference is an article on industrial innovation in 1978. Articles dealing directly with construction innovations emerged primarily in the late 1980s and early 1990s.

EDITORIAL PROCEDURES

A number of resources were used to locate the literature included in this bibliography. The University of Michigan MCAT Library Catalog served as a starting point. From there searches were run in different index databases such as: Wilson Indexes to Journal Articles, Engineering Index Online, and American Society of Civil Engineers Online Database. Many of the articles, books, and dissertations included a list of references and these in turn were included in the bibliography. Various Internet search engines were used to generate the web site section.

The annotations were written by the authors of this bibliography solely to describe the original literature in a succinct manner so construction people and students can easily and quickly survey the literature on construction innovation to select, obtain, and study that which is most pertinent to their interests and needs. The writing style is brief and terse to be quickly read, and it departs from normal grammar that would make it less succinct. Annotations have not been reviewed or endorsed by original authors, and they should not be used as substitutes or surrogates for the original sources. We apologize for inaccuracies or errors we may have made in our interpretation and reporting.

ACKNOWLEDGMENTS

This research was funded through the Construction Innovation Scholar Program of the Construction Innovation Forum. The CIF recognizes and encourages innovation in the construction process or in materials, design, equipment, detailing, contract administration, labor relations, management, training, procurement and other areas

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through its Scholar Program, annual NOVA Awards and Innovation Celebration Banquet, Internet Web Site www.cif.org, NOVA Awards Mock Jury, and support of other construction innovation programs and awards.

Abernathy, W. J. and Utterback, J. M. (1978). "Patterns of Industrial Innovation." *Technology Review*, MIT Press, 80(11), 40-47.

Presents a model of patterns in innovation within companies as they mature; fluid pattern, transitional pattern, and specific pattern. The capacity and methods of innovation evolve as companies move from small technology-based enterprises to high-volume producers. Argues that small, entrepreneurial organizations and larger organizations producing standard products in high volume are at opposite ends of a spectrum. Technological innovation in high-volume product industries such as light bulbs, paper, and steel tend to produce incremental innovations and rely on mass marketing and economies of scale. This specific pattern results in cost reduction and is the driving force behind these innovations. The fluid pattern is associated with the identification of an emerging need or a new way to meet an existing need. This is entrepreneurial in nature. Companies producing product innovations from the fluid pattern tend to be in affluent markets located near universities and research institutions. These organizations are usually small and have greater flexibility and adaptability. Their product innovation offers superior functional performance and tends to offer higher unit profit margins. As a company develops a product towards large-scale manufacturing, the innovation goals, which were once ill-defined and uncertain targets, become well-articulated design objectives. Maturing companies become more formal and develop more levels of authority. Understanding this transition can help companies to continue innovating.

Ahmad, I. (1991). "Restructuring Responsibility and Reward for More Construction Innovation." *Preparing for Constr. in the 21st Century: Proc., Constr. Congress 1991*, L. M. Chang, editor, ASCE, 453-458.

Proposes restructuring current U.S. contract systems to facilitate innovation. Problems and obstacles that discourage technology innovations are identified: liability, government regulations, codes, and performance risks. Modified contract systems allow forces responsible for innovation to be motivated and rewarded for their efforts. Competitive bidding impedes innovation, because it provides little margin for a contractor to implement new techniques or upgrade quality of its current product. Discussion of construction as a service industry and as a job-shop manufacturing process is used to describe types of innovation. Two basic models of contractual relationships are presented based on the service concept and job-shop concept. Concludes that innovation is possible only when major participants (owner, designer, contractor) are committed. Design-build contract provides best atmosphere for innovation, because it changes adversary relationship between designers and builders into a joint venture relationship. Product and process innovations become responsibility of one entity, the design-build firm.

Bauman, R. D., and Kracum, J. J. (1995). "Innovation – What More Can We Do?" *Proc., 1995 Constr. Conference*, C. W. Ibbs, editor, ASCE, 65-69.

General editorial on state of innovation in construction industry. Innovation barriers are financing, government regulations, public and political pressures, environmental constraints, and socio-economics. Public support for construction projects is essential, as public is both an ally and customer. Government regulations and policies provide institutional barriers for construction, the "granddaddy of barriers." Calls for sharing risks among institutions, engineers, and public. All benefit from innovation. Engineers should be flexible, recognize that changes will be made, and use this to stimulate innovation. Engineers should not be constrained by funding when developing a project. When solution meets criteria of users, alternative-funding sources can be developed. Design-build is beneficial, and owners should allow construction to start during design phase. Design-build allows contractor and designer to work together closely, so the most current materials, means, methods can be incorporated into work. "Innovation requires a shift in paradigm, one from acceptance of the standard norm to the acceptance of change."

Becker, J. M. (1986). "Rowes Wharf: A Case Study in Substructure Innovation." Constr. Innovation: Demands, Successes and Lessons, Proc., Constr. Div. of ASCE in conjunction with ASCE Convention, Seattle, Washington, C. B. Tatum, editor, ASCE, 1-10.

Case study examines decision making involved in construction of mixed-use project located adjacent to historic Boston Sconce (South Battery). Project consists of 575-car below-grade garage, 100 residential condominiums, 330,000 square feet of office space, 230-room hotel, ferry terminal facility, retail shops, marina, and public open spaces on 5.38-acre parcel. Case study reviews decisions that led to adoption of an up/down construction procedure. Up/down construction starts with installation of caisson foundation followed by simultaneous construction of superstructure and excavation of below-grade portion. Up/down technique minimized some construction risks including slurry wall leakage, excavation work delay due to weather, and tieback use during construction. Major issue became risk of innovation. Up/down construction had not been performed in U.S. prior to this project, so no available firms had direct experience with construction method. This meant delay could result from poor planning, unforeseen technical problems, lack of coordination, etc. Thus risks of innovation were offset by benefits from economic and schedule incentives and minimization of some construction risks. Entire up/down construction process for this project is described, with illustrations. Unique combination of proven construction procedures made up/down construction a success.

Bernold, L. E. (1991). "Learning and Innovating in a Construction Technology Laboratory." *Preparing for Constr. in the 21st Century: Proc., Constr. Congress 1991*, L. M. Chang, editor, ASCE, 478-483.

Construction Engineering and Management program at North Carolina State University created a laboratory facility for students to discover new techniques for common construction tasks. Students used their knowledge of basic engineering principles, construction technology, computers, and mechanical and electronic systems. Tools available to students included state of art computers, robot arms, sensors, conveyors, specialty boards for voice recognition, and data acquisition software. Two undergraduate students developed a prototype brick masonry robot. Emphasizes need to foster creative and innovative problem solving in students of construction technology. Course is an example for other educators of construction.

Bernstein, H. M., Kissinger, J. P., and Kirksey, W. (1998). "Moving Innovation Into Practice." *Civil Engrg. In the Asia Region: Proc., First Int. Civil Engrg. Conf.*, E. A. Downey, ASCE, 250-259.

In the past few years innovation and collaboration have distinguished successful companies from others. Civil Engineering Research Foundation (CERF) was founded to encourage innovation and collaboration throughout the construction industry. NES-Building Innovation Center collaborates with National Evaluation Service to serve building and residential industry. Innovation process involves four key steps: (1) generalization or conceptualization of idea, (2) development and production of new technology, (3) transfer of knowledge, and (4) subsequent application to solving problems. Presents benefits and barriers to innovation and describes CERF innovation centers. CERF is a founding member of the World Federation of Technical Assessment Organizations (WFTAO) and has an international presence. CERF is particularly interested in working with key organizations in countries that do not have assessment organizations. Process of creating innovation centers in U.S. can be applied to Asia.

Bernstein, H. M., and Lemer, A. C. (1996). *Solving the Innovation Puzzle*. ASCE, New York, N.Y. 127 pp.

Excellent overview of current status of construction innovation. Innovation is critical for U.S. to sustain role in global marketplace. Environment and incentives for innovation in U.S. including methods to fund research and potential barriers. Calls for renaissance in design and construction; "a return to youthful vigor, freshness, and productivity." Historical examples of innovation are discussed, including Brooklyn Bridge and Empire State Building. Analyzes innovation cultures in Europe and Japan; methods they use to fund research and development in construction, and transferable lessons applicable to U.S. design and construction. Lays out four-part strategy for sustaining innovation and lists specific actions to encourage innovation in U.S. design and construction.

Billington, D. P. (1996). *The Innovators: The Engineering Pioneers Who Made America Modern.* John Wiley & Sons, Inc., New York, N.Y., 256 pp.

Excellent book details history of engineering innovators in America from late 18th century to late 19th century; uniquely written from engineering perspective. Sidebars with formulas and calculations help readers see and understand basic calculations used by these engineers for their designs. Book divided into two parts. First part comprised of iron, steam, and early industry from 1776-1855; early bridge structures and prominent designers of period, in-depth history of steamboats, discussion of textile industry and power network created to sustain it. Second part titled "Crossing the Continent, 1830-1883" focuses on transcontinental railroad development. Other chapters discuss development of mass production techniques for steel, Thomas Edison's development of light network, and John Roebling's design of Brooklyn Bridge. Last Chapter is on 1876 Centennial Exhibition in Philadelphia. This fair provided "an archaeological storehouse for those engineering developments in the U.S. that were transforming society in the nineteenth century." All works of modern technology have "a scientific basis, a social context, and symbolic power."

Carr, R.I. (2000). "Detroit Owner's Role in Construction Improvement." ***J. Const. Innovation,*** **Construction Innovation Forum, prepared for Construction Detroit CEO Summit, www.cif.org, 2 pp.**

Discusses means by which major owners (buyers of construction services) in Detroit and Southeastern Michigan can act as leaders in construction improvement. Major owners have power to (1) use contractor construction improvement programs as criteria in qualifying contractors for projects, (2) insert and enforce appropriate contract clauses, and (3) participate with others driving change in Southeast Michigan construction. Each $1 billion of construction creates more than 40,000 new jobs in construction supply and service industries, of which 10,000 are in construction industry itself. Local contractors are criticized for hiring travelers from other states instead of recruiting young people as pre-apprentices and apprentices. Local contractors have been unable to provide enough jobs for all who have entered apprenticeship programs. "Detroit is missing its chance for thousands of good, well paying careers that would not only build a young, diverse, local construction work force but would help rebuild a strong Detroit middle class."

Carr, R.I. (1997). "Engineering and Construction Management Leadership and Opportunity." ***J. Const. Engrg and Mgmt.,*** **ASCE, 123(3), 292-296.**

Adaptation of 1996 Peurifoy Lecture for journal. Discusses basic development of Construction Engineering and Management (CE&M) and the parallels with author's career. Describes launch of CE&M graduate programs in mid-1950s. Current status of CE&M programs, growth of these programs, backgrounds of early faculty who pioneered these programs, CE&M's relationship with the American Society of Civil Engineers (ASCE) and its home in the Construction Research Council. Introduces initiatives within CE&M, innovations, role of engineering in CE&M research, and research needs. Further research in needed in describing construction processes; constructing the design from working drawings; quality of construction documents; methods of packaging documents for site work; construction sequencing; documenting actual construction; construction worker knowledge; safety and ergonomics; construction impact control; erection stresses, tolerances, measurements, and damages; and problems associated with subcontractors. Two primary objectives of CE&M faculty are to (1) provide in-depth CE&M teaching and research to engineers preparing for a CE&M career and (2) provide basic CE&M to engineers in design areas of civil engineering and to engineers in other engineering disciplines interested in constructed facilities. Concludes with general comments on university CE&M programs and direction CE&M is heading.

Carr, R.I. (1998-present). "NOVA Award Mock Jury Kit." ***Construction Innovation Forum,*** **www.cif.org, updated annually.**

Mock Jury Kit is tool for construction, civil engineering, and architecture students to perform their own analysis of NOVA Award nominations. Kit is downloaded as .zip file and contains two .pdf files and an Excel spreadsheet. Mock Jury participants are given same information furnished to real NOVA Award Jury. Kit includes "Notes for Nomination Screening Meeting," sample NOVA Award nomination form, and spreadsheet that can be used by Mock Jury to tabulate results. In addition, participants need to review current year's "NOVA Award Nominations" booklet that can be downloaded from www.cif.org. Describes NOVA Award selection process. Nominations are narrowed down to shortlist and then given to investigators for an in-depth study and report. Students determine their own shortlist, which can be compared to the real shortlist. Mock Jury students learn current state of construction technology and innovation and practice group decision-making.

Carr, R.I. and Harris, R.B. (1994). "Construction Industry Innovates to Protect Environment." ***Engrg News Record,*** **June 6, 1994, 232(23), E35-E40.**

Describes growing number of environmental-related nominations for Construction Innovation Forum's NOVA Award. Trend in nominations shows remarkable strides construction industry is making as it grapples with environmental aspects of its work. Environment-related innovations fall into three categories: innovations in treatment or remediation, recycling of material, and reducing environmental impact. Briefly describes innovations in treatment and remediation including jet-grouted laminar diaphragms, off-site fabrication of gas storage and sludge digester tanks, soil remediation system, lightweight fire water lagoon liners, and a molded plastic, arch-shaped leaching chamber. Material recycling innovations include recycling of asphalt pavement, portable and reusable road mats, and reverse formwork using ash aggregate controlled density fill. Environmental impacts are reduced by innovative replacement of steam generators at a nuclear power plant, resource efficient housing project, and confinement concrete reinforcement. Innovations that reduce soil disturbance are densely compacted aggregate piers, microtunneling, self-propelling trench shoring machine, aluminum hydraulic trench shoring system, and Osterberg load cell that determines soil capacities for drilled shafts, piers, and driven piles.

Carr, R.I. and Lane, R.W. (1999). "Construction Industry Innovation." Keynote at First General Session, 1999 Business Roundtable National Construction Conference, Ponte Verde Beach, Florida, November 15, 1999*, www.cif.org/Presentations/BRT/BRT_Talk.htm*.

Introduces Construction Innovation Forum (CIF) as grass-roots, non-profit organization started in 1986. Goals are to recognize and encourage construction innovation. Membership is owners, contractors, building trades, unions, architects, engineers, faculty, and suppliers. Describes NOVA Award selection criteria and process. Demonstrates resources and features available at CIF web site (www.cif.org) including lists of NOVA Award winners and finalists, downloadable Mock Jury kit, keyword searchable database, *Journal of Construction Innovation*, nomination forms, and banquet information. Describes Detroit Energy Construction Innovation Program as example of owner's role in innovation, which saved $200 million on one project. Suggests ways owners can start construction innovation initiative by finding, developing, and using innovations, requiring contractors and vendors to innovate, recognizing innovations on their own projects, and supporting CIF.

Carr, R.I. and Maloney, W.F. (1983). "Basic Research Needs in Construction Engineering." *J. Const. Engrg and Mgmt.,* ASCE, 109(2), 181-189.

Paper describes discussions that occurred at a basic research needs workshop at University of Michigan sponsored by National Science Foundation. Leading academic researchers discussed basic research needs in construction industry. Defines basic research in construction engineering and management by reporting participant comments. Describes four primary areas of construction basic research: (1) construction engineering management; (2) construction engineering analysis and design; (3) construction engineering uncertainty; and (4) construction engineering human resource management. Construction engineering management research needs are task planning and design, quality control/quality assurance, project planning, estimation, measurement, and control, organization and industry structure, and strategic planning. Construction engineering analysis and design research needs are roofing system construction, materials handling, temporary support structures, construction equipment, and environmental variations. Construction engineering uncertainty research needs include range estimating, structural failure and construction safety, contractual risks, bidding and markup analysis, decision theory, and process and project simulation. Construction human resource management research needs include worker motivation, training, labor force, leadership, labor relations, safety, personnel functions, and group dynamics. Basic research will advance construction engineering and management to the level of knowledge expected of the engineering profession.

Carr, R.I. and Maloney, W.F. (1982). "Final Report, Workshop on Construction Engineering Basic Research." *Dept. of Civ. Engrg,* Univ. of Michigan, August 1982, 70 pp.

Report on discussions that occurred during a workshop at University of Michigan sponsored by National Science Foundation and Construction Research Council of American Society of Civil Engineers. See entry above for article in *Journal of Construction Engineering and Management* that gives brief description of topics covered in report.

Chang, L., Hancher, D. E., Napier, T. R., and Kapolnek, R. G. (1988). "Methods to Identify and Assess New Building Technology." *J. Constr. Engrg. and Mgmt.,* ASCE, 114(3), 408-425.

Joint research project between Purdue University and U.S. Army Construction Engineering Research Laboratory (USA-CERL); research objective was to develop a formalized mechanism to identify new building technologies for U.S. Army Corps of Engineer construction program. Used six different methods to identify new technologies; a periodical search, reviewing building code reports, perusing U.S. Patent and Trademark Office's computer database (Lexis), soliciting innovations through advertisements in periodicals, contacting testing organizations, and relying on a list of experts supplied by industry magazine editors. Standard format was created to input acquired data. Researchers try to identify innovative technologies having greatest impact potential. Researchers developed "impact factor" based on cost and volume of construction technology encompassed in military construction for Army (MCA) building program. Factor represents potential impact of technology to help rank technologies that should be investigated. High impact factor technologies were analyzed for cost/benefit, risk, and feasibility. Results using Generic framework produced encouraging results. Others can use methodology to identify the potential of innovative construction technologies.

Christensen, C. M. (1997). ***The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail.*** **Harvard Bus. School Press, Boston, Mass., 225 pp.**

Tracks innovation in different industries including hard disk drive industry, steel industry, discount retail and department stores, personal digital assistant industry, motorcycle manufacturers, and mechanical excavator manufacturers. Describes disruptive technologies versus sustaining technologies. Sustaining technologies foster improved product performance and can be discontinuous or radical in nature or incremental. Sustaining technologies improve performance of established products. Emerging disruptive technologies occasionally have worse product performance, at least in short term. But these disruptive technologies commonly precipitate failure of leading firms. Defines problem and management of disruptive technologies. Discusses internal and external validity of failure framework. Internal validity comes from application of failure framework to disk drive industry. External validity comes from application to multiple industries. Four laws of disruptive technology are: (1) Companies depend on customers and investors for resources. (2) Small markets don't solve growth needs of large companies. (3) Markets that don't exist can't be analyzed. (4) Technology supply may not equal market demand. Discusses how managers can harness these forces rather than fight them.

"*Construction Innovation Forum: Annual Report.*" (1990-present). Construction Innovation Forum, R.I. Carr, editor, updated annually.

Report distributed at annual Construction Innovation Forum's NOVA Awards Banquet, limited to each year's NOVA Award Winners and nominations. Report gives brief introduction of Construction Innovation Forum (CIF). Lists board of directors, members, sponsors, jurors, and investigators. Majority of report is one-paragraph descriptions of nominated innovations that include names and addresses of people to contact for further information..

"Construction Innovations: NOVA Award Winners and Nominations 1990-1995" **(1995). Construction Innovation Forum, R.I. Carr, editor, 63 pp.**

Catalog of construction innovations nominated for the NOVA Award in the six years 1990-1995. Each NOVA Award winner is featured in a one-page description that includes color photographs that also lists individuals primarily responsible for the innovation, and gives a name and address of a person to contact for further information. Each nominated innovation is described in one paragraph plus contact information. Innovations are arranged alphabetically by year. Catalog also presents general information on the CIF.

"Construction Technology Needs and Priorities" **(1982). Report B-3, Business Roundtable, 22 pp.**

Research identifies areas of technological need in construction. Questionnaires sent to selected owners, contractors, and designers in building, light industrial, heavy industrial, and power plant construction with 128 responding. Conducted interviews with 51 craft superintendents and field engineers on 14 major job sites across U.S. Identifies three areas that have highest potential for technological innovation and comprise significant portion of construction costs: piping, electrical work, and installation of mechanical equipment. Each sector of construction identified different areas for technological improvements. Building construction sector identified structure, enclosure skin, interior finishes, and electrical work. Structure, piping, and electrical work were identified by light industrial sector. Heavy industrial and power construction both identified piping, mechanical equipment, and electrical work. Report illustrates technologies that could be developed to improve typical work activities associated with piping, electrical work, and mechanical equipment installation. Concludes that significant cost savings will result from technological innovations.

Dulaimi, M. (1995). "The Challenge of Innovation in Construction." ***Building Research and Information,*** **23(2), 106-109.**

Reports U.K. construction industry attitude toward innovation and research and development. Innovation is difficult unless a company has a "firm foundation" built on R&D. Needs an environment conducive to innovation. Between 65% and 80% of new technologies introduced in U.K. fail. Development of a "systematic approach to managing new ideas through research and development is essential." Defines innovation and ideas of "technology-push" and "demand-pull." Describes environment corporations use to succeed at innovation. Questionnaires sent to fifty-four contractors, consultants, and material and component manufacturers. Inquiries on company attitudes toward R&D, perceptions of benefits of R&D, reasons for lack of R&D activities, perceptions of risk, difficulty in managing innovation, sources for identifying new technologies, and university involvement in R&D. Calls for U.K. construction industry to invest more in R&D and develop greater appreciation for nurturing innovative ideas.

Everett, J.G. (1994). "Automation and Robotics Opportunities: Construction versus Manufacturing." ***J. Const. Engrg and Mgmt.,*** **ASCE, 120(2), 443-452.**

Automation and robotics is frequently cited as a solution to construction industry skilled labor shortage, declining productivity, increasing costs, safety, and quality control. Some construction processes lend themselves to automation, because machines excel at physically intensive tasks requiring speed, strength, repetitive motions, and operation in hostile environments. Others do not. Studies have tried to determine types of construction work best suited to automation. Kangari and Halpin developed "robotics feasibility" score to rank processes by need, technology, and economics. Discusses construction field operation taxonomy. Understanding taxonomy leads to appropriate level for automation and robotics. Gives background and definition of construction projects' seven levels: project, division, activity, basic task, elemental motion, orthopedics, and cell. Overview of approaches to automation in manufacturing including Motion Time Measurements. Construction work is often repetitive, but cycles are much more complex than mass production. Engineers and architects design only down to activity level and have little incentive to be concerned with field work intricacies. Automation in manufacturing cannot be transferred to construction; instead construction must develop its own strategies. Discusses future research needs.

Foundation for a New Approach to Implement Building Innovation (1996). CERF Report #96-5021, ASCE, New York, N.Y. 35 pp.

Research report published through Civil Engineering Research Foundation (CERF). Report is end result of Partnership for Building Innovation, which focused on developing national strategy for partnerships between public and private sector to implement new technologies in building sector. Discusses problems in current approach to innovation. Presents preliminary framework for encouraging more innovation. Primary focus of framework is enhanced evaluation for new technologies. Requires cooperation and risk sharing among technology developers, testing agencies, construction companies, insurance community, and building owners.

Gerwick, Ben C. (1990) "Implementing Construction Research." ***J. Constr. Engrg. and Mgmt.,*** **ASCE, 116(X), 556-563.**

Brief, concise paper says much research on construction innovation has been in U.S. while most development has occurred overseas. Local development has been hindered by short-term money pay-offs, which does not benefit construction industry. Lists benefits of development and provides investigation results proving weak U.S. government, and general contractor support of development. Conversely, several research institutes in Japan and Europe provide strong support. Three-page description of T-headed bar is example of innovation originating in U.S. but commercially developed by Norway consultants, a European manufacturer, and Canadians. Three figures illustrate how bars are used. Encourages globalization of innovation, involvement of manufacturers and contractors worldwide.

Gerwick Jr., B. (1989). "Transferring Construction Innovation into Practice: Lessons Learned." ***Excellence in the Constructed Project: Proc. of Constr. Congress I*****, R. J. Bard, editor, ASCE, 530-533.**

Discusses trials and tribulations of author's experience with innovation in construction. Author's vision for innovation was greatly influenced by creative genius of his father, who believed an innovation was ultimately successful when successfully applied on a contract project. His father used innovative ideas to develop low bids and then to complete the projects successfully. Discusses iterations taken to develop high durability, prestressed concrete piles in lengths up to 150 ft and innovative use of slurry-trench diaphragm walls in San Francisco. Slurry-trench diaphragm wall was success, but it failed commercially for author's company. A competitor used it on Embarcadero Station. Author invoked patent rights, which led down long and litigious path. Presents three more innovation cases demonstrating "value of a systems approach, the need for aggressive and persistent exploitation despite early set-backs, and the unsatisfactory benefits from patents and licenses as opposed to direct application by the innovator." Concludes that attitude within a company is of utmost importance; "the spirit of encouraging and demanding innovation and the willingness to take educated risks, which lead to successful commercialization of innovation."

Ioannou, P.G. and Carr, R.I. (1988). "Advanced Building Technology Matrix System." ***J. Const. Engrg and Mgmt.,*** **ASCE, 114(4), 517-531.**

Advanced Building Technology (ABT) Matrix is an information database system to describe and document advanced building technologies. As cost of industrial building construction increases, introducing new technologies that enhance quality, increase construction efficiency, and decrease costs has become a critical to staying ahead of competition. "In order for these new technologies to be incorporated in building construction, however, they must first be identified and evaluated during the project design phase and the construction planning phase." Architects/Engineers access to available or future technologies is limited to advertisements in trade journals or magazine articles. Research objective of ABT development includes providing owners, designers, and contractors with standardized, structured information on state of the art building technologies. Documentation format includes technology name, classification, application, description, benefits, limitations, special problems, repair, costs, properties, and contact information. Scope of project was limited to five technology categories: floor, roof, structure, wall, and miscellaneous. ABT Matrix and Spec-Data sheets and Manu-Spec sheets compliment each other. Information in ABT Matrix is intended to be impartial and is maintained by user, whereas spec-data sheets are produced by manufacturers and resembles a form of controlled or constrained advertising. ABT documentation used Final Word II and Lotus 1-2-3 software. Study documented 151 ABTs for enclosure systems of light industrial and commercial buildings.

Ioannou, P.G. and Liu, L.Y. (1993). "Advanced Construction Technology Systems - ACTS." *J. Const. Engrg and Mgmt.,* ASCE, 119(2), 288-306.

Advanced Construction Technology System (ACTS) is continuation of the Advanced Building Technology Matrix project reviewed in previous entry. ACTS is computerized database to classify, document, store, and retrieve information about emerging construction technologies. Project is result of industry wide effort to speed technology transfer, and promote efficiency and effectiveness. Primary objective is to allow user to find all emerging technologies related to a specific discipline or area of construction and provide sufficient information for user to decide whether the technology merits further research. Database includes 25 predetermined fields that give sufficient information on a technology for an initial decision of interest. Four ACTS prototypes were developed over three year period. Discusses merits of different database software. Classification system was taken from Masterformat and Uniformat used in U.S. and European CI/SfB coding system. Keywords used for information retrieval. Presents figures from database software and discusses user and administrator privileges. ACTS is an effort to speed up construction technology transfer by systematically surveying, evaluating, organizing, and disseminating technology information to owners, designers, and contractors.

"Integrating Construction Resources and Technology into Engineering" (1982). Report B-1, Business Roundtable, 18 pp.

Reports comprehensive study of current philosophies, practices, and problems with integrating construction expertise into project planning and engineering design stages. Report resulted from interviews with owners, architects, engineers, and contractors in commercial, power, light industrial, and heavy industrial construction markets. Recommends that construction experts participate in conceptual development, decision-making, design reviews, scheduling, and cost estimating. This is commonly called "constructability" or the planned involvement of construction in design process. Construction technology lags behind partly due to contractor's typical role in construction. Contractors build from a complete set of drawings, which limits incentive to innovate. Constructability programs involve contractors in design where they suggest cost saving methods. Cost and duration can be reduced by new construction technology and integrating construction expertise with project engineering.

Kangari, R. and Miyatake, Y. (1997). "Developing and Managing Innovative Construction Technologies in Japan." *J. Const. Engrg and Mgmt.,* ASCE, 123(1), 72-78.

Large Japanese construction companies believe developing innovative technology is key to growth. They focus on adapting business strategy to technological innovation for future competence. Paper is based on construction in Japan and targets Japanese companies. Innovation development concepts are applicable to other countries. Briefly discusses four main factors related to innovative construction technologies: strategic alliances, effective information gathering, reputation through innovation, and technology fusion. Figure illustrates main stages of technology evaluation for selecting high impact technologies. SMART system technology case study demonstrates how the four factors led to innovative automation of high-rise building construction. Figures show detailed operation of system components. Firms must gather information by reaching out and synthesizing outside technology. Crucial link between innovation and business is forecast of long-term technology integrating present actions and future vision.

Kissinger, J. P., and Edwards, S. (1997). "CERF Innovation Centers – Collaborative Evaluation Services for the Design and Construction Community." *Constr. Congress V: Proc. of the Conf.*, S. D. Anderson, editor, ASCE, 348-355.

In recent years innovation and collaboration have distinguished successful companies from others. Civil Engineering Research Foundation (CERF) was founded to encourage innovation and collaboration throughout construction industry and serve as a “facilitator, coordinator, and integrator.” CERF’s primary goal is to expedite movement of research from universities and laboratories into practice and to promote adoption of new technologies throughout construction industry. Leading industry organizations and associations were approached and their support was sought in developing Highway Innovative Technology Evaluation Center (HITEC). Success of HITEC led to creating two more innovation centers: Environmental Technology Evaluation Center (EvTEC), and Civil Engineering Innovative Technology Evaluation Center (CEITEC). Describes CERF’s strategic alliances and Applied Research and Technology (ART) program. Given widespread support for HITEC, EvTEC, and CEITEC, they have initiated over sixty new product evaluations as of 1997. CERF is a critical link in technology transfer of new innovations and continues to foster collaboration to advance construction and design industry.

Laborde, M., and Sanvido, V. (1994). “Introducing New Process Technologies Into Construction Companies” *J. Const. Engrg and Mgmt.,* ASCE, 120(3), 488-509.

Well-structured and prepared paper presents ideas supported by many research reviews and results. Defines innovation as seeking and implementing new technology to improve functions of companies and emphasizes need to improve innovation. Ultimately presents guidelines for introducing new technologies in companies. Proposes process for implementing innovation to contractors based on current models and findings from six case studies. Begins by analyzing innovation models. Categorizes questions for innovators and innovation users. Figure and table summarize interview results used to develop innovation process model. Simplified model is shown in figure. Main stages of model are explained and presents guidelines for innovation. Illustrates different models for small and large contractors. Characteristics of innovative companies are discussed.

Madewell, C. J. (1986). “Innovative Solutions to the Challenges of Heavy Civil Projects.” *Constr. Innovation: Demands, Successes and Lessons, Proc., Constr. Div. of ASCE in conjunction with ASCE Convention*, Seattle, Washington, C. B. Tatum, editor, ASCE, 11-17.

Describes conditions on several projects where innovation solved problems. Common innovation benefits include increased efficiency, cost savings, and competitive advantage. Innovations on example projects were products of experience and perseverance of key players. Describes unique scaffolding system used on Golden Gate Bridge restoration project needed to keep traffic unimpeded. A special rigging system installed modular steel panels weighing 20 tons. No holes or welds were permitted in steel panels. Submerged arc welding was employed due to damp, sea air conditions, and nighttime construction. New Melones Reservoir diversion tunnel in California featured a field fabrication yard to assemble 23 ft diameter by 80 ft long tunnel sections. Special equipment was developed to transport 170-ton sections. An innovative welding procedure was used. Finite element stress analysis on Hanford Waste Storage Tanks project aided tank fabrication and reduced costs. Some of these innovations were imaginative solutions to a construction specification, and others were an alternative to traditional methods, but all involved perseverance and hard work.

Moavenzadeh, F. (1985). “Construction’s High-Technology Revolution.” *Technology Review*, MIT Press, Oct. 1985, 32-41.

Brief history of trends and developments in construction. Construction advanced at rapid rate during 1960s and was far ahead of foreign competitors. 1970s brought environmental impact statements, building restrictions in historic districts, and community participation in major projects. These government regulations added additional delays and costs. Construction is ready for another technology revolution. Infrastructure decay provides an impetus. Computers, robotics, and advanced materials are being integrated into construction. Describes new technologies in each of these areas. Suggestions for overcoming barriers to innovation in construction, including need for a comprehensive research and development program, which require industry, government, and university cooperation.

Nam, C. H. (1990). “The Process of Product Innovation in the Building and Heavy Sectors of the U.S. Construction Industry.” PhD thesis, Dept. of Civil Engrg., Stanford University, California. 362 pp.

Discusses ten successful product innovations to prove and disprove five hypotheses. Reviews existing construction innovation literature. Extensive background on design of research methodology. Detailed case studies of product innovations are provided from ten projects. Product innovation success involves synthesis of problems with technology. Most product innovations did not come from external sources. Owner involvement and commitment led to greater use of product innovations. In most cases the key person involved in product innovation was an engineer with high technical competence. Current U.S. contract system does not favor innovation. System could benefit from integrating design and construction functions. Also important are owner leadership, developing long-term relationships among organizations, and employing integration champions.

Nam, C. H., and Tatum, C. B. (1991). "Case Method to Educate Innovation Champions in Construction." ***Preparing for Constr. in the 21st Century: Proc. of Constr. Congress 1991*****, L. M. Chang, editor, ASCE, 484-489.**

Outlines goals and objectives for a course exploring management of technology for construction innovation. Course primarily used case studies and a discussion-oriented approach to develop skills students needed to be future innovation champions. Course was developed as a result of extensive research into innovation process in U.S. construction industry. Course was structured to challenge students' critical thinking skills. Students were required to participate in class discussions, present a case study and lead classmates in analysis of the case, provide feedback to other student presenters, propose a research paper, and submit a term paper.

Nam, C. H., and Tatum, C. B. (1988). "Major Characteristics of Constructed Products and Resulting Limitations of Construction Technology." ***Constr. Mgmt. and Economics*****, 6(2), 133-148.**

Well presented, comprehensive, and persuasive paper based on numerous researchers' findings, quotations, and reports from 1950s to 1980s. Summaries keep arguments clear to reader. Authors identify some limitations of their ideas and suggest areas of further studies. Research continues investigation of mechanisms and strategies for technological advances and increased competitiveness in construction and references previous research. Examines fundamental causes of construction technological phenomena to identify directions in developing technology. Discusses five major characteristics of constructed products: immobility, complexity, durability, cost, and social responsibility. Analyzes limitations of two summarized results: consequences of site operations, and specialization. Examples include mass production, 'lock system', and separation of design and construction. Concludes that construction limitations offer opportunities for new practical applications. Long-term goals and broad view of design and construction enhance exploitation of new construction technology. Highlights future research topics.

Nam, C. H. and Tatum, C. B (1989). "Toward Understanding of Product Innovation Process in Construction." ***J. Const. Engrg and Mgmt.,*** **ASCE, 115(4), 517-534.**

Well-structured, argumentative paper emphasizes importance of product innovation to technological advancement, construction productivity, and U.S. economy. Helps reader understand product innovation and promotes innovation process in construction. Author's ideas and thoughts are underlined by facts, reasons, and quotations originally from designers, researchers, and scholars. Uses research hypotheses and findings from 1980s to argue that cause of decline in construction productivity is due to inadequate research on product innovation. Two pages of brief reviews on research results in 1980s on general nature of innovation process including its characteristics, major driving forces to innovation, and influential factors. Illustrates simple model of product innovation process developed from research results. Describes characteristics of and relationships among four key factors in model: owner's demand, problems, designer technology, and contractor process technology.

"*NOVA Award Nominations*." (1998-present). Construction Innovation Forum, R. I. Carr, editor, www.cif.org, updated annually.

Compilation of each year's NOVA Award nominations in Adobe Acrobat .pdf file format, which anyone can view by browser or download, print, and distribute. Each nomination consists of (1) one page of text that describes the innovation and provides the name and addresses of a person to contact for more information and (2) one page of photograph(s), schematic(s), advertisement(s), or other material that describes the innovation. Booklet is distributed to NOVA Award Jury for their use in selecting a shortlist of nominations for further investigation.

Peters, T. J., and Waterman, R. H. (1982). ***In Search of Excellence: Lessons from America's Best-Run Companies*****. Harper & Row, New York, N.Y. 360 pp.**

Excellent companies go the extra mile to foster, nourish, and care for "product champions." These individuals believe so strongly in their ideas that they do whatever it takes to push their products through the system to the customer. Capturing this innovative culture was a primary goal of this research. Presents eight basic principles that were developed from an extensive study of successful companies such as Boeing, Delta Airlines, 3M, IBM, and Hewlett-Packard. Action – do something rather than sending questions through cycles and cycles of analyses and committee reports. Learn preferences of your customers and cater to those preferences. Break large companies into smaller companies to encourage creative thinking, independence, and competition. Encourage employees to give their best efforts by allowing them to share in rewards of company's success. Upper management must stay in close contact with firm's essential business. Companies should stick to the business they know best. Fewer administrative layers and fewer people at upper levels are essential. Foster a climate with dedication to central values of company along with a tolerance for employees who accept those values.

Petroski, H. (1997). *Remaking the World: Adventures in Engineering.* Vintage Books, New York, N.Y. 256 pp.

Primarily a selection of essays published in a column by author for magazine *American Scientist*. Highlights wide range of engineering adventures and engineering pioneers from several engineering disciplines. Touches on history of some of world's greatest engineering feats and innovators who played key roles in bringing these projects to fruition. Explores how engineering intertwines and is sometimes driven by society, technology, and politics. Projects are wide ranging and include development of steam engine, and construction of Channel Tunnel, Hoover Dam, Ferris Wheel, Panama Canal, and Petronas Towers in Kuala Lumpur, Malaysia. Engineers highlighted include Karl Terzaghi, John Scott Russell, James Nasmyth, and Karl Steinmetz.

Slaughter, E. S. (1993). "Builders as Sources of Construction Innovation." *J. Constr. Engrg and Mgmt.,* ASCE, 119(3), 532-549.

Innovation occurs more frequently in construction than is recognized. Innovation is more common from on-site workers than from manufacturers or researchers. Research investigates and identifies 34 innovations of a single technology, the stressed-skin panel as used by residential constructors. Results indicate "users" of new technologies (i.e. contractors and trades workers) are potential sources of innovations and modifications. Manufacturers can tap the skills and experience of users to improve their products versus attempting to improve products through their own research. Manufacturers have little incentive to innovate and can effectively control products and pricing, because they have few competitors. On-site innovating by skilled labor can effectively reduce costs and improve quality. Research includes an extensive, field-based study of residential construction innovations identified through interviews. Users proposed integrating stressed skin panels into total building system, while manufacturers concentrated on innovating within the system itself. Manufacturers commercialized few innovations identified by users, connections to other building systems despite their potential improvement to overall panel performance.

Slaughter, E. S. (1998). "Models of Construction Innovation." *J. Constr. Engrg. and Mgmt.,* ASCE, 124(3), 226-231.

Presents five categories of innovation: incremental, modular, architectural, system, and radical innovations with hope that construction companies can develop more effective strategies for identifying, acquiring, developing, and implementing innovations. Discussion of key differences between innovation in manufacturing and construction and how existing models must be modified to reflect unique characteristics of construction activities. Innovations range from incremental to radical. Five categories of innovation are defined, with examples. Extensive discussion of strategies to incorporate innovations within projects. These frameworks can reduce perceived risks of construction innovation and encourage innovation throughout industry.

Slaughter, E. S. (1991). "Rapid Innovation and Integration of Components: Comparison of User and Manufacturer Innovations Through a Study of Residential Construction." PhD thesis, Dept. of Civil Engrg., Massachusetts Institute of Technology, Boston. 264 pp.

It is commonly thought that residential housing builders never innovate. Detailed field-based study of a single technology found widespread innovation from builders rather than manufacturers of products and materials. Comprehensive study of stressed-skin panel use in residential construction. Structured interviews provided data on 34 user innovations to stressed-skin panels. Previous research focused on user innovations commercialized by manufacturers. Understanding of non-commercialized user innovations developed in field was limited. Field-based nature of study identified innovations used in "real time" with tight time and cost constraints. Manufacturers commercialized few innovations identified by users, especially ideas enabling panels to connect to other building systems despite their potential improvement to overall panel performance. Research demonstrated previously unexplored differences between user and manufacturer innovations.

Tatum, C. B. (1986). "Demands and Means for Construction Innovation." *Constr. Innovation: Demands, Successes and Lessons: Proc., Constr. Div. of ASCE in conjunction with ASCE Convention*, Seattle, Washington, C. B. Tatum, editor, ASCE, 31-43.

Buildings are becoming more complex. Owners are asking for advanced construction technology to reduce costs. Foreign competitors are regularly innovating. These three trends create demands for construction innovation.

Innovation can provide a major competitive advantage for construction companies. Construction requirements for building construction, light industrial construction, and process and power construction are becoming more complex. Owners' want increased cost effectiveness on their projects as cited by Business Roundtable Construction Industry Cost Effectiveness reports. Foreign competitors are spending much more money on construction research and development. They are developing advanced tunneling techniques, using robotics in construction, placing greater emphasis on technology, and applying these new technologies effectively as a basis for competition. Organizational influences on construction innovation are presented. Ways to innovate in construction are suggested. Uniqueness of each construction project presents many opportunities for innovation. Individual initiative on projects creates "champions" for using innovation. Construction input into design phase increases innovation opportunities. Other industries can provide new technologies that have construction applications.

Tatum, C. B. (1991). "Incentives for Technological Innovation in Construction." *Preparing for Constr. in the 21st Century: Proc. of Constr. Congress 1991*, L. M. Chang, editor, ASCE, 447-452.

Several examples of successful construction innovation were studied to determine incentives for innovation. Owners call for better performance and flexibility from new facilities. These provide ripe opportunities for increased technical capability from designers and contractors. Design-build contracts enable successful development of unique technical capabilities. Organizational culture encourages innovation to win and perform projects. Owners demand continuous improvement of construction process to increase quality and decrease project duration and cost. Each construction project is unique and presents unique innovation opportunities. Sustaining an innovative environment and nurturing new ideas will encourage individual "champions" and provide incentives for innovation. Gives specific actions to be taken by senior managers to create innovative culture. Lists strategies for firms to develop competitive edge through innovation. Managers can foster innovation through continuous process improvement. Specific actions for integrating innovation with operations. Incentives to innovate indicate barriers can be overcome with some risk.

Tatum, C. B. (1983). "Innovations in Nuclear Concrete Construction." *J. Constr. Engrg. and Mgmt.,* ASCE, 109(2), 131-145.

Informative but complex and technical paper strongly illustrated by numerous examples. Unique technical requirements and scope of concrete work raise significant nuclear construction challenges. Difficulties and challenges have provided experience and innovation that can benefit other construction segments. Discusses several lessons learned from nuclear projects including innovative approaches in engineering scope, construction input, work planning, special techniques, and quality assurance. Describes such technical requirements as structural design criteria, embedded systems, and plates. Examples of engineering scope: scale models, specific details at complex blockouts, and penetrations. Examples of construction input include planned sequences and implementation steps. Special techniques used in nuclear projects and adapted to other construction areas: slip forming, form support systems, and yard pre-assembly. Explains quality assurance program details.

Tatum, C. B. (1989). "Managing for Increased Design and Construction Innovation." *J. of Mgnt. in Engrg.*, ASCE, 5(4), 385-399

Well-organized paper argues that an increase in innovation in design and construction is crucial to improve productivity and to increase competitiveness in construction. Manager and private and public owner guidelines to increase innovation. Develops necessary managerial actions using analyzed information from a few successful innovations in construction firms in 1980s. However, there are few examples, proven principles, or facts. Two page brief review of research results from 1980s regarding management for innovation. Explains ideas behind and nature of some key management actions: maintaining strategic vision of technology, understanding risks associated with innovations, creating technological challenges and encouraging leadership, fostering unbridled planning, and prompting internal and external integration. Conclusion reinforces effects of management and technology strategies. Future research should explore new management techniques for development and effective implementation of advanced technology.

Tatum, C. B. (1989). "Opportunities for Innovation in Construction Equipment and Methods." *Excellence in the Constructed Project: Proc. of Constr. Congress,* R. J. Bard, editor, ASCE, 223-231.

Strong opportunities exist for innovation in construction equipment and methods. Former public works projects are moving into private sector. Owners demand "more construction for the money," and projects become more complex. New technologies developed in other industries have construction application. Foreign competitors are entering U.S. construction market. Industry is ripe with opportunities to improve existing equipment and advance construction techniques. Analyzes historical development of construction equipment and methods and opportunities for future innovation using framework developed from technological advancements in other industries. Describes recent breakthroughs in construction equipment and incremental improvements in construction equipment and methods. Outlines key actions that can be taken by equipment suppliers, equipment users, designers and owners of construction facilities, and researchers to facilitate technological advancements.

Tatum, C. B. (1989). "Organizing to Increase Innovation in Construction Firms." *J. of Constr. Engrg. and Mgmt.,* ASCE, 115(4), 602-617.

Investigates twenty construction innovation examples to identify characteristics of construction firms that embrace innovation. Methodology involves detailed interviews with persons directly engaged with innovation. Data gathered was used to improve descriptions of innovative processes and identify similarities in organizational and managerial actions in innovative construction firms. Research found innovative firms tend to have a long-term viewpoint. Managers assume a broader view of risk. Use of innovation was vertically integrated throughout all project phases. Planning was given high priority. These firms also sustain an innovative culture. Identifies critical roles within innovative firms including design and construction visionary, operations iconoclast, management, commercial and technological champions, and technological gatekeeper.

Tatum, C. B. (1986). "Potential Mechanisms for Construction Innovation." *J. Constr. Engrg. and Mgmt.,* ASCE, 112(2), 178-191.

Technological advancements differ among construction segments. Reviews background knowledge on process innovation, possible advantages and disadvantages to construction innovation, possible mechanisms to foster construction innovation, and research areas needed to increase rate of technological advancement in U.S. construction industry. Reviews previous studies on innovation in heavy civil and transportation construction, building construction, and industrial and power construction. Market structure, firm size, and stage of development influence innovation. Product and market characteristics identified several characteristics that favor successful innovation: (1) attention to user needs and marketing, (2) product uniqueness, marketing knowledge, technical and production synergy, (3) in-depth understanding of customers and market. Champions and entrepreneurs are critical and include technical innovator, business innovator, product champion, and chief executive. There have been a limited number of investigations into construction innovation. Many research directions are possible including contrasting construction with manufacturing industry, looking at prior innovation research, examining differences in construction and the advantages and disadvantages of innovating. In-depth presentation of construction innovation advantages and disadvantages. Possible sequence of investigation for construction innovation: (1) development of a classification system of construction operations, (2) exploring the fundamental mechanisms of innovation in construction, and (3) identifying long-term strategies for construction technological advancement.

Tatum, C. B. (1984). "What Prompts Construction Innovation?" *J. Constr. Engrg. and Mgmt.,* ASCE, 110(3), 311-323.

Six examples of construction innovation from nuclear generating plant projects identify conditions that foster construction innovation. Common conditions for innovation include engineering and construction requirements that challenge current technology, a schedule allowing for detailed examinations of alternative construction means and methods, and an energetic individual "champion." Project management personnel must be willing to make objective cost and schedule comparisons and to positively approach alternative construction methods. Managers who coordinate the design team need to allow for early detection and resolution of problems resulting from changes caused by alternative method. Conditions commonly present on sites that incorporated innovation included available new technologies, firm serving as both designer and constructor, methods successfully used on past projects on a much smaller scale.

Tatum, C. B. and Funke, A. T. (1988). "Partially Automated Grading: A Construction Process Innovation." *J. Constr. Engrg. and Mgmt.,* ASCE, 114(1), 19-35.

Describes process innovation leading to development of laser-aided grading systems. Compares development process of innovation to a previous model of innovation process. Develops practical applications for increasing rate of innovation in construction. Extensive review of existing laser application in construction. Inefficiencies and frustrations with current methods of grading. Even small projects require several pieces of equipment. There is waiting time between survey/layout crew and construction crew. In situ conditions commonly do not match contract documents. Reference stakes for grading are restricted to areas with good visibility. Operators must be highly skilled for fine grading, which makes the operation costly. Relates vision and resources of a contracting firm president who was devoted to development of this innovation. Manufacturers were not interested in developing this technology as they felt it would comprise too small a market, so contractor developed it himself. Much iteration led to the final success. Setbacks included hydraulic systems overheating, erratic controls, unstable stands to hold laser equipment, lasers that were not self-leveling and requiring extensive set up time, stray laser signals from building reflections, operators refusing to use new technology, and suppliers' unwillingness to support this new use of laser technology. End results included improved performance, fine grading with a small crawler-tractor, and a competitive advantage. Competitive advantage enabled contractor to move from $500,000 annual volume in 1976 to over $50,000,000 in eight years. Partially automated grading conforms well to Stanford Construction Innovation Project model and shows that practical application of innovations requires vision and patience.

Uwakweh, B. O. (1991). "Managing Technology Innovation in Construction." *Preparing for Constr. in the 21st Century; Proc. of Constr. Congress 1991*, L. M. Chang, editor, ASCE, 459-464.

Proposes framework for managing construction technology process innovations. Liability, code requirements, intense competition, industry structure, and profit are common barriers. Foreign firms threaten U.S. construction firms. Decaying U.S. infrastructure makes innovation vital. Technology innovation is multi-stage process. Phases include idea/generation, feasibility, market and technical analysis, model/process development, and introduction and implementation. Construction technology innovation can be successfully managed through selection of personnel, participative decision-making, and a compensation and reward system. Selection of key personnel is an important tool for fostering innovation.

CONSTRUCTION INNOVATION WEB SITES

The following section covers websites and electronic journals related to construction innovation. The Internet is changing at a rapid pace, and these are the most current sites at the time of publication.

"Built Environment Innovation & Construction Technology." (2000, 2001). <http://www.dbce.csiro.au/inno-web/1000/index.htm>, <http://www.dbce.csiro.au/inno-web/0401/index.htm> (May 16, 2001).

Internet websites consist of the Number 15, October 2000 edition and the Number 18, April 2001 edition of *Built Environment Innovation & Construction Technology*, a bi-monthly magazine. Website disseminates news on high-impact, new technology, products, and services related to built environment. Lists about ten headlines, each introduced with one-sentence description. Titles of headlines link to corresponding articles, each presented with two pages of background information, short descriptions of design, building processes, features, functions, products. Some items illustrated.

"Civil Engineering Research Foundation." (1999). <http://www.cerf.org> (May 12, 2001).

Internet website designed for professionals and the public to understand how construction industry can be advanced through research. Website contains huge amount of information but many hyperlinks make it hard to find desired details. Links to a few pages of explanations on how Civil Engineering Research Foundation (CERF) tries to move innovation into practice by fostering research, with emphasis on costs, quality, and safety. Brief 10 page description of various research programs underway and how they can provide better solutions to management and technical problems. Links to technology evaluation centers, started from 1997: Highway Innovative Technology Evaluation Center (HITEC), Civil Engineering Innovative Technology Evaluation Center (CEITEC), and Environmental Technology Evaluation Center (EvTEC). Centers provide details on how to move innovation into practice in areas of highways, public works, the environment, and buildings. Link to IIEC, created in 1999, deals with energy efficiency, renewable energy, and integrated transport planning. Links to CERF newsletters, press releases, reports and organizations.

"CII Emerging Technologies." (2001). <http://www.new-technologies.org/ECT> (May 13, 2001).

Internet website helps people learn basic ideas of construction innovations resulting from research. Hyperlinks to more than 100 high-impact emerging construction technologies. Technologies are classified as civil, mechanical, internet-based, electrical, and others. Civil section is the largest, containing almost 60 technologies. Most technologies have a two-page fact sheet that describes need, how the technology works, advantages and disadvantages, status, contacts, and references.

"Construction Education." (2001). <http://www.constructioneducation.com/indexjou.htm> (May 14, 2001).

Internet website designed for people search and read interesting construction literature. Includes both site map and alphabetical index to extensive site information. Site map lists forty construction categories such as construction materials, services, and management. Categories link to hundreds of related websites, mainly publications in journals, magazines, records, reports, and newsletters. Lengths of publications vary up to over a hundred pages. Alphabetical index can be used if name of desired material is known. Headline news links to about 25 entries of news in such construction industry areas as real estate, workers' compensation, labor relations, and bonds.

"Construction Industry Institute (CII)." (2000). <http://construction-institute.org> (May 12, 2001).

Internet website has comprehensive CII Products Catalog designed for quick and easy product information. Products include publications, reports, and videotapes intended to improve CII companies' business performance and competitiveness of construction. Website provides three ways to find products: knowledge areas, subject index, and numerical indices. Each product has one-paragraph description of content, amount of content, published date, price, and detailed information links.

Thirteen CII knowledge areas are listed, including planning, design, operations, controls, organization, people, and globalization. Knowledge areas subdivided into best practices and proposed best practices. Best practice is a process or method that leads to enhanced project performance. Within product groupings, products are listed in reverse chronological order. The subject index links common industry terms to related catalog areas and specific products. Numerical indices can be used if unique name of product is known. Indices are classified as benchmarking and metrics, education modules and implementation resources, research reports, report summaries, and videotapes.

"Construction Innovation Forum." (2001). <http://www.cif.org> (May 17, 2001).

Internet website promotes construction innovations that improve quality and reduce cost of construction to professionals and public. Aims to teach them importance of innovation and encourage involvement in innovative processes. Contains database where one can search over 350 Nominations for the NOVA Award by titles, keywords, or nomination year. Search yields one-paragraph description of innovation with contact person and address. Hyperlinks to 2000 and 2001 NOVA Award winners, finalists, and nominations. Each nomination has one page of general description and explanation on how innovation functions and one page of illustrations. Hyperlinks to calls and suggestions for new 2002 NOVA Award nominations. Qualifications, application requirements, and method of submission are stated. Hyperlinks to details on CIF's annual banquet, conferences, and scholars program. Mock Jury link gives instructions and processes for current year participants. Contains this paper, "Construction Innovation – An Annotated Bibliography" of papers, reports, and web sites on construction innovation.

"Construction Innovation: New to Arnold for 2001" (2001). <http://www.arnoldpublishers.com/Journals/Journpages/14714175.htm> (May 10, 2001).

Internet website covers ten pages of important information on Construction Innovation, a new international journal first published earlier this year that hopes to be published quarterly. Journal serves students up to postgraduate level, academics, researchers and professionals who are interested in current developments in different aspects of information technology in the construction industry. Disseminates research results, communicates new practical ideas, applications and case studies to professionals to maintain competitiveness. Website lists journal's new key features, editorial board, and provides information for authors. Also shows a photo of journal's cover, price and a sample copy request form for people who are interested in subscribing online. Hyperlinks to other sites of interest and engineering journals: Building Services Engineering Research & Technology (BSER&T) and Lighting Research & Technology. Contacts for any queries are available at the end of the website.

"Engineering News Record." (2001). <http://www.enr.com> (May 14, 2001).

Internet website contains *Engineering News Record*, a weekly magazine providing business, technical news, and analyses for decision makers in construction. Magazine covers major projects, technological achievements, markets, finance, costs, labor, construction methods, equipment, materials, government legislation, management, and significant worldwide events. Subscribers include contractors, engineers, architects, owners, government officials, suppliers, producers, and academics.

Website organized by indices that allows fast and easy access to information. A few hyperlinks to such highlights as cover story and feature stories. Highlights are presented with titles, authors, published dates, brief descriptions of content, tables, figures, graphs, and photos. Headline news index allows readers to select reading news on buildings, environment, transport, and information technology. Hyperlinks to lists of a few hundred ranks for firms in design, contracts, environment and management. Sourcebook link has a paragraph of coverage, amount of content, a photo cover, price, and ranking tables. Products and services index links to mailing lists, available editions, prices, and orders for additional copies and article reprints.

"Infrastructure Innovation Bibliography." (1998). <http://iti.acns.nwu.edu/clear/infr/ce3.html> (May 16, 2001).

Website approximately fifteen pages in length, divided into three sections: civil engineering, construction, and infrastructure; concrete materials and structures; roads and bridges. First section lists 50 related bibliographies, second section lists 10, and third section lists 30. Bibliographies written between 1980's and late 1990's. Most references are papers and reports published by civil engineering organizations.

"Journal of Light Construction." (2001). <http://www.jlconline.com/jlc/> (May 15, 2001).

Internet website for *Journal of Light Construction*, a monthly magazine that educates builders and remodelers about construction. Website shows current issue's cover and previews its main features. Lists weekly headline news. Each headline has a title linking to a few pages of description of a particular topic. Figures and photos illustrate procedures and materials involved. Hyperlinks to articles related to electric, business, structures, roofing, exteriors, and interiors. Hyperlink to forums containing message boards for building professionals to communicate effectively. Hyperlink to bookstore that lists book topics and presents monthly book specials with a few sentence descriptions. Industry links directory lists trade associations, educational and research institutions, and other non-profit organizations serving the light-construction industry. Live events link directs construction training shows online, used as a demonstration for professionals to learn and understand building techniques.

"National Research Council of Canada's Institute for Research in Construction." (2001). <http://www.nrc.ca/irc/newsletter/toc.html> (May 10, 2001).

Internet website lists and links to six volumes of *Construction Innovation*, a journal published by the National Research Council of Canada's (NRC) Institute for Research in Construction. Journal is primarily written for Canadian construction practitioners. Typical issues have 30 pages of comprehensive news of recent research results in materials, fire management, building, transportation, and indoor environment systems. Also includes product evaluations, code developments, and conference highlights. Published quarterly, with each volume divided into four numbers. The first issue was published in July 1995 and the latest is Volume 6, Number 1, published in Winter 2001. Sections are well organized and presented with tables and annotated diagrams that help illustrate results and ideas. Website also links to the Institute for Research in Construction's (IRC) homepage and publications.