Technology Transfer: An Industry Point of View

by D. E. Stephan

Synopsis: Technology transfer within the construction industry is difficult due to (i) organization of the industry, (ii) lack of construction industry participation in research, (iii) societal impediments. These barriers are discussed in relation to transferring innovation to practice.

Differing activities that can mitigate the barriers are discussed and recommendations are offered to enhance the transfer of technology from research results to application in the construction industry.

Keywords: Construction; construction management; evaluation; research

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INTRODUCTION

Technology transfer, the incorporation of innovation into practice, within the construction industry is recognized as a difficult problem. Many of the impediments found within the United States (US) are also common in varying degrees in other countries. The problems are caused by several industry characteristics which can be categorized as follows:

(i) Organization of the industry.
(ii) Lack of construction industry participation in research.
(iii) Structural social impediments.

BARRIERS TO TECHNOLOGY TRANSFER

Organization of the Construction Industry

The organization of the US construction industry is fragmented into many small companies who operate, for the most part, in limited geographical areas. Over 80 percent of the firms are very small with less than 10 employees, two-thirds have less than five employees [1]. Services are bifurcated into design and construction. Design is performed by professional business entities. Construction is performed by specialized business entities organized around a trade (specialty contractors) with a non-trade business unit (general contractor) coordinating and scheduling the specialty contractors' activities. This organizational structure creates a very large and diverse audience with widely varying interests and economic motivations. This significantly impedes the efficient transfer of innovations into practice. Communication with and within such a diverse group is difficult. There is substantial capital and intellectual investment in the status quo by all parties. An innovation which is perceived as advantageous by one group is often viewed as threatening by another.

The fragmented structure also results in low levels of capitalization relative to the economic volume of business activity. This means that any capital required by an innovation will have to compete with other uses for a very scarce resource.

The organization of the construction industry results in diversity of both economic interest and expertise, complicated communication, and low capitalization among all of the economic units involved in construction. This fragmentation creates a difficult maze through which an innovation must move if it is to be incorporated into practice.

Industry Research and Development

If industry is involved in the creation of innovation, the efficiency of transfer of the innovation into practice is greatly enhanced. Unfortunately, the US construction industry has a dismal investment rate in research and development as indicated by Table 1.

The low level of investment by the US construction industry as compared to other industries is due to the lack of a rational basis for investment [2]. This is primarily due to procurement systems for the constructed project based upon price only selection and the inability to achieve a return on R&D investment due to the bifurcated delivery system and the use of prescriptive specifications.

Simply put, investment in R&D does not improve business performance for designers or constructors. Designers do not have a financial incentive to utilize new technologies. In most cases, utilizing or specifying new technologies increase the designer's cost and risk of doing business without financial reward or benefit. The constructor has marginal ability to introduce new technologies because he is divorced from the design. In the US, construction contracts are prescriptive rather than performance based. The constructor can only execute the work in accordance with the documents he has contracted against; that is to say, "as designed". This greatly reduces the opportunity for innovation. In addition, innovation often entails new procedures and unknowns which can increase the constructor's risk; a strong disincentive under a price only selection system.

If the construction industry invested in research and development, technology transfer would occur automatically because a return on investment can only be achieved when the innovation is employed in practice. Unfortunately, the irrationality of industry investment in R&D is a formidable barrier to technology transfer.

Societal Impediments to Technology Transfer

Societal impediments in the US primarily take the form of a dysfunctional legal system. Construction disputes between users, owners, designers, constructors and suppliers are rapidly escalating. The number of construction lawyers has grown from approximately 2,000 in 1985 to over 4,000 in 1989 [3]. The cost of the US tort system in 1986 was $108 billion; 2.6% of the 1986 GNP [4]. It is estimated that number now exceeds $200 billion.

The constructed project often directly impacts public safety; thus participation in the construction industry entails special social responsibilities manifested by professional and contractor licensing requirements. Public safety and a litigious environment demand a universal and responsive evaluation system for innovation to assure safety and efficacy. Unfortunately, such an evaluation system does not exist in the US environment of multiple codes and standards. Some progress has been made in the area of manufactured product evaluation; little progress has been made in the area of process, engineering science and material science evaluation.

Need for Overcoming Barriers to Technology Transfer

The existence of these formidable barriers to the application of innovation begs the question of whether it is proper to challenge them. Perhaps their very existence warns us that construction is an inappropriate industry for innovation; an industry where the "status quo" should be maintained. I would argue that this is not the case.

Construction and construction-related activities constitute approximately 13 percent of current US Gross Domestic Product (GDP), employing over 6 million people in the US [1]. It is the second largest contributor to GDP. Constructed facilities provide the renewal and expansion of the infrastructure that is essential for a modern industrial society to function effectively and provide an acceptable quality of life for its citizens. Construction impacts all aspects of a national economy. The economic efficiency of that economy is largely governed by cost effectiveness and functionality in its infrastructure system. The cost of any manufactured product or delivery of a service is directly impacted by the cost effectiveness of the constructed physical plant, the constructed distribution systems and constructed support systems such as water, power, communication and waste disposal. Thus, we must overcome the barriers of transferring construction innovations to practice if we are to enhance and advance mankind's standard of living. The efficiency and the quality of the constructed facilities must be of paramount concern as they determine the quality, efficiency and effectiveness of a society's economic activity and relative quality of life.

High performance concrete and the transfer of the enabling technologies for achieving high performance concrete to practice is essential to advancing the efficient delivery and maintenance of infrastructure. The research results, knowledge and innovations yielding high performance concretes must overcome the barriers and move from the laboratory to application as rapidly as prudently possible so the benefits can be realized by both the construction industry and society.

TRANSFERRING TECHNOLOGY

Evaluation

Codes and standards are often considered a barrier to the application of innovation. In fact, they can enhance technology transfer by defining proper application of a technology, documenting the performance and characteristics of a technology and disseminating knowledge that a technology is ready for application. Institutions such as the American Concrete Institute (ACI), which develop and promulgate codes and standards, are the technology gatekeepers for concrete. The institutions currently determine technology acceptance. This acceptance is essential for the widespread use of a technology. Timely and efficient evaluation and acceptance is essential if research is to warrant industry investment. Evaluation and acceptance is crucial to technology transfer from the laboratory and technical paper to practice. The gatekeeper role precedes the market force determination of efficacy. The investment in high performance concrete (HPC) research justifiably requires efficient evaluation and acceptance of the results, as appropriate, so a return on the research investment is possible. Lyle H. Schartz, director of The National Institute of Standards and Technology (NIST) materials science and engineering laboratory is quoted as stating "The codes on which Civil Engineers are operating are out-of-date. We need to ensure that new materials are available that will allow roads and bridges to last twice as long to justify the money spent under any new infrastructure program" [5].

The need for evaluation means that codes and standards responsive to high performance concretes and their use must be developed in a timely fashion. The HPC program currently being pursued in the US promises major investment by both government and industry in developing HPC materials and procedures for their use. The research will be both basic and applied. The applied research will include development. The proposed program entails funding for technology transfer and demonstration projects. This means that those providing research funding and the researchers need to consider and provide for technology transfer. Researchers can and should develop their findings to include design and use procedures to facilitate evaluation of the resulting technologies and the training necessary in their use.

Competent evaluation of innovation removes major societal barriers by providing responsible public protection and life safety considerations in the use of new technologies. In addition, comprehensive technical evaluation provides protection for the users and implementors of new technologies by establishing their prudence within the context of the U.S. legal system.

Training

From industry's perspective, training in new technologies is essential to the transfer of innovation to practice. Training can overcome the inefficiencies and risks associated with new technologies.

Publication of research results is an appropriate end product for basic research. If technology transfer is to be facilitated, publication of research results is not an adequate product for applied research. Practicing engineers have expressed frustration at "another unusable technical paper" on a subject and pleaded for "inclusion of design procedures" to make the research meaningful to them. Where appropriate, effort needs to be made to have research projects and their funding include technology transfer by including in the deliverables, at some stage, draft design procedures and/or draft standards for the use of the technology so industry and technology gatekeepers can efficiently handle the absorption of the new technology. Too often the procedures for the use of an innovation are developed through trial and error experience due to the lack of research guidance. This is a very inefficient process.

Proper use of technology is essential to successful application. Successful use of various high performance concretes will undoubtedly demand special procedures in their manufacture and use and development of unique practices that will require training of both designers, constructors, suppliers and craftsmen.

Information Dissemination

Our fragmented industry makes communication of technical advances very difficult. Expanding general awareness of new technology and technological development enhances its transfer to use. Familiarity facilitates acceptance; unfamiliarity raises unnecessary suspicions and doubts. Widespread knowledge of developing technology also increases the probability of financial support of additional research.

Institutes such as ACI have placed a major emphasis on the publication of peer reviewed technical papers and sessions presenting technical information. These efforts are necessary but reach a limited audience and are, of themselves, an ineffective way of transferring innovation to practice.

Our diverse industry needs easy access data bases on current research underway and associated published research findings. The data bases should separately delineate research findings or research in progress on the developmental aspects of a technology such as use and application procedures.

One of the best ways of disseminating information is to actively involve multiple parties in the process of developing information. Because the construction industry has limited experience in funding and participating in research and because of its fragmented nature, ACI and other technology gatekeepers would provide an invaluable service if they would form multi-company consortiums from industry; including designers, constructors, manufacturers and suppliers, to fund and participate in research projects together. In the United States, HPC research and the transfer of new HPC technology would be greatly enhanced if ACI would form industry consortiums to fund and participate in HPC research, particularly as it reaches the development stages and, through the use of ACI's technical membership, provide oversight of the industry funded HPC research projects.

CONCLUSION

The application of research requires widespread dissemination of results, evaluation of the results and training in the use of the results if some of the more formidable barriers to technology transfer are to be overcome.

From industry's perspective, if we can lower the barriers to technology transfer and move innovation to practice efficiently, we will see industry demand for and support of research that will outstrip our capacity to advance the state-of-the-art. The beneficiaries of the timely and efficient transfer of technology affecting construction will be society, through the efficient delivery of its infrastructure and enhancement of its quality of life.

RECOMMENDATIONS

Industry and the American Concrete Institute cannot, by themselves, overcome all the barriers to transferring concrete technology, but we can address a number of them by instituting and supporting the following:

- A recognized national evaluation system of innovation, including products, material science and engineering science, by expert panels.

- Codes and Standards based upon science as well as experience.

  Greater emphasis on development aspects of research and development with applied research deliverables including:

  (i) draft codes and standards or revisions to existing codes and standards, and

(ii) application procedures for the innovation (i.e., design procedures, recommended practices, etc.).

- Formation of industry consortiums for research funding and participation with oversight provided by ACI technical membership.

- A five (5) year rolling file containing abstracts of current research pertaining to concrete.

- Development of training materials in the use of HPC for the designer, constructor, supplier and craftsman.

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TABLE 1—COMPARATIVE U.S. INDUSTRY INVESTMENT IN RESEARCH AND DEVELOPMENT[6]

Sector	Annual Industry R&D Investment (% of annual sales)
Electrical/Electronics	5.4
Telecommunications	4.7
Aerospace	4.1
Chemicals	3.8
Automotive	3.4
Construction	**0.5**

Self-Compactable High-Performance Concrete in Japan

by Hajime Okamura and Kazumasa Ozawa

Synopsis: Self-compactable high performance concrete requiring no consolidation in situ has been recently developed in Japan to improve the reliability of concrete and concrete structures. This concrete is a significant material innovation for a new generation of concrete structures. A review of the concrete and the applications are described.

Keywords: Compacting; consolidation; high-performance concretes

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CONCEPT OF SELF-COMPACTABLE HIGH PERFORMANCE CONCRETE

Concrete is one of the essential structural materials for constructing the infrastructure of the society. However, careful placing by skilled workers on site is vital for constructing durable and reliable structures. In other words, reduced durability resulting from improper placement is a serious defect of concrete. To improve the reliability of concrete, it is necessary to develop a concrete, which is not affected by workmanship during placing, or self-compactable concrete requiring no consolidation [1].

The self-compactable concrete can not only produce durable and reliable concrete structures, but also save labor, eliminate the consolidation noise, lead to the innovation of construction systems, and realize the modernization of concrete construction. Many new construction methods and materials that have recently been developed will find wider applications if they are combined with self-compactable concrete.

In the summer of 1988, the prototype of self-compactable concrete was successfully completed by combining materials on the market [2]. This prototype proved to have satisfactory performance with regard to drying and hardening shrinkage, heat of hydration, denseness after hardening, and other properties. Simultaneously, this concrete was named "High Performance Concrete".

The prototype is proportioned to have a slightly lower coarse aggregate content and a higher powder content than conventional air-entrained concrete (**Table 1**). Its slump flow is designed to remain unchanged for 90 minutes after mixing by the use of a low-slump-loss-type superplasticizer, which is a material essential for enhancing the flowability without increasing the unit water content.

In addition to ordinary portland cement, fly ash, granulated blast-furnace slag and an expansive admixture are employed as powders. Fly ash is used for enhancing the flowability without increasing the water content and the heat of hydration. Fine granulated blast-furnace slag contributes to adjusting the grading of ordinary portland cement. The expansive admixture is for compensating the early-age shrinkage. A small dosage of a viscosity agent is added to impart adequate viscosity. The prototype of High Performance Concrete was realized with limited drying shrinkage, limited heat of hydration and adequate strength, in addition to the self-compactability.

Having succeeded in developing the prototype, the authors conducted an open experiment, inviting more than 100 engineers to the campus of the University of Tokyo in 1989, and the experiment created a sensation among the guests. Since then, a number of experiments to confirm the self-compactability have been conducted by many researchers in major construction companies. The self-compactable concrete has been used in Japan for a number of projects such as bridge girders, bridge towers, bridge piers, LNG tanks, culverts and buildings. Precast concrete plants are producing the products by using the self-compactable concrete on a commercial basis mainly because of the prevention of noise from vibrating machines.

Recently the authors [3] published the system for designing the mix proportions of the standard type of self-compactable high performance concrete, which uses neither powder materials, except the moderate heat portland cement, nor viscosity agents.

METHODS OF ACHIEVING SELF-COMPACTABILITY

Self-compactable concrete requires high deformability without segregation of materials. The increased viscosity of the paste is effective in inhibiting segregation (**Fig.1**). "Antiwashout underwater concrete" is a kind of self-compactable concrete placed underwater, in which segregation is strictly inhibited by the addition of a high content of a viscosity agent, so as to prevent the cement particles from dissolving into the water. It is therefore not suitable for reinforced concrete structures in air, since the viscosity is so high that entrapped air may not easily be released and the concrete may not easily pass through congested reinforcing bars.

Self-compactable concrete with a viscosity agent is an antiwashout concrete with reduced viscosity, so as to be applicable in air. *Takeshita* et al. produced self-compactable concrete for the first time by this method, and attempted to apply it to actual structures [4]. The balance between the viscosity agent and the superplasticizer is important for increasing self-compactability. However, there is a limit to increasing self-compactability