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GOALS FOR EDUCATION AND RESEARCH IN CONSTRUCTION[A]

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INTRODUCTION

This paper summarizes results of a policy-level workshop attended by a distinguished group of construction people representing owners, contractors, government, and educators. The April f975 workshop was funded by the National Science Foundation and was sponsored by the Construction Institute at Stanford University. In 2 full days of frank far-reaching deliberations, these industry leaders attempted to define basic problems that the industry will face in the years ahead.

In specific terms, the workshop was designed to: (1) Identify basic research needs in the management of construction; and (2) define and formulate goals for basic research in this area. The participants' efforts were concentrated in four general subject areas, including: (l) Manpower and organizational development; (2) management methodologies; (3) innovations in construction methods; and (4) construction industry dynamics. Before outlining the results, however, this paper will consider the nature of basic research and its relationship to construction.

BASE RESEARCH IN CONSTRUCTION

The meaning of "basic research" is subject to continuing debate. To link the terms "construction" and "basic research" would appear to invite a paradox. "Construction" implies designing and building facilities to meet specific needs. Most of the industry's research advances come from solving specific problems when encountered on new projects; often this involves applied scientific and engineering research of a very high order.

On the other hand, "basic research" implies investigation of fundamental

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concepts or principles, but with no conscious intent that it lead to tools that are expected, much less guaranteed, to solve problems. For example, Einstein's now-famous (though once obscure) basic research led to the equation relating mass and energy. Yet it took a long evolution through further basic research, applied research, and development to the eventual engineering, design, and production that we now see in nuclear power plants or machines that cure cancer.

There are many ways to describe basic research. Some characterize it as "long-range" and "theoretical." as contrasted to short-term applied problem solving. Others say it means the problem itself has not been defined yet, Perhaps more relevant than a general definition of basic research would be an assessment of its role. Bush, head of the World War II Office of Scientific Research and Development, made such a statement in his 1945 report to President Harry S. Truman (I). In explaining the need for an agency to support basic research, he said:

> Such an agency, moreover, should be an independent agency devoted to the support of scientific research and advanced scientific education alone. Industry learned many years ago that basic research cannot often be fruitfully conducted as an adjunct to or a subdivision of an operating agency or department. Operating agencies have immediate operating goals and are under constant pressure to produce in a tangible way, for that is the test of their value. None of these conditions is favorable to basic research. Research is the exploration of the unknown and is necessarily speculative. It is inhibited by conventional approaches, traditions, and standards. It cannot be satisfactorily conducted in an atmosphere where it is gauged and tested by operating or production standards.... Research will always suffer when put in competition with operations.

Bush's statement predated by 3 yr the establishment of the National Science Foundation. As overseer of much of the World War II research effort. he was intimately familiar with the role of basic research in breaking new ground in which to plant seeds of applied research and development. With a few word changes, most of what he said could apply directly to construction.

Many would still object that the construction industry simply cannot afford the "luxury" of basic research while clear and urgent problems go begging for answers. To some, basic research conjures up images of impractical. "blue sky," "ivory tower" theoreticians whose seeming unconcern for potential economic returns borders on being irresponsible. And yet, this intolerance for risk and delay is ironic in an industry that has its share of gamblers.

Others, however, argue that construction must invest in basic research if it is to cope with increasingly complex projects in the future and reverse its declining productivity compared to other industries. Taking this adieu: the workshop sought to define the role of basic research in construction and to outline some promising areas of investigation.

CONSTRUCTION INDUSTRY

The construction industry itself meets another meaning of paradox, that of "something with seemingly contradictory qualities," In its share of the nation's gross national product it is the largest industry, but the vast majority of its hundreds of thousands of participants are small businesses. Its firms are intensely competitive among themselves in the best tradition of the free enterprise system, yet compared to other industries its technological advances sometimes appear trivial.

Construction is highly fragmented and sometimes divisive, yet in response to pressing national needs, such as a major war effort, few industries can mobilize resources more quickly. Each of its elements – designers, constructors, regulators, consumers, suppliers, crafts – can be highly skilled in its own areas, yet there is little general perspective on how all the pieces fit together. There really is no central focus.

Construction is very custom-oriented: there is a strong feeling that if something is unique, it is better. Yet this also means that the industry has been slow to respond to the benefits of mass production. Its structure is specialized and layered, with complex interlocking interests and traditions. Its character makes it highly effective on practical or project matters, yet often ineffective on general or program matters.

Needless to say, basic research falls in the latter category of the less practical and more general and speculative. Accurate data are not available, but it is generally assumed that only a fraction of 1% of the industry's gross revenues are invested even in applied research let alone basic research. This is in strong contrast to industries such as electronics, where an estimated 15%-20% of revenues go into research and development. This, in turn, at least partially accounts for the quantum leaps that industry has taken in recent years.

It has been observed that the construction industry is almost completely incentive-oriented. If there is little research and almost no basic research, it is likely that there is little incentive for investing in it. This probably results in part because advances in construction tend to result from innovations or "better ideas." Most of these cannot be protected either by secrecy or patents and thus disseminate rapidly through the industry. Thus, there is little incentive for one firm to invest heavily in research that can soon he expected to equally benefit its competitors. If there is to be an increased research effort in construction, and particularly a deliberate move into basic research, incentives will most likely be provided through nontraditional means. This subject will be examined later in the paper.

CHALLENGES IN CONSTRUCTION'S FUTURE

The most profound recent developments in construction are seen as the increasing size of many of its projects and organizations, the increasing techno-logical complexity of such projects, more complex interdependencies and variations in the relationships between its organizations and institutions, and proliferating regulations from government. At the project level, management has just begun to integrate design, procurement, and construction into one total process. There are now and will continue to be shortages of resources, including materials, equipment, skilled workers, and technical and supervisory staff. There will be more and more governmental regulation of: (1) The safety of the design and of field construction methods; (2) the environmental consequences of projects;

and (3) personnel policies at all levels. Management must also cope with the new economic and cultural realities resulting from inflation, the energy crisis, changing world development patterns, and new societal standards. These trends have been accelerating and will most probably continue into the future. Fig. 1 summarizes some of the elements that are involved. Despite continuing economic problems, there is an ongoing need (or the construction industry to expand and improve its capabilities and its scope of operation to meet changing and, in the long run. growing demands for its services.

QUALIFICATIONS AND LIMITATIONS ON SCOPE AND OBJECTIVES

Before proceeding to the findings of the workshop, it is important to recognize the qualifications and limitations that were assumed in its scope and objectives.

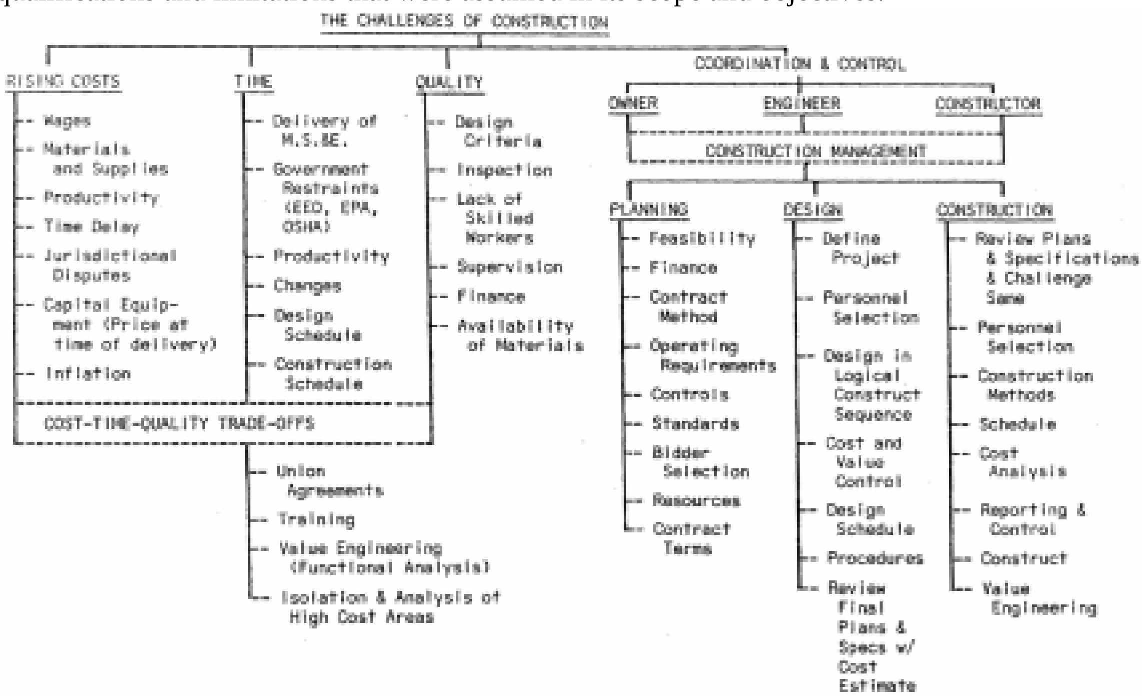

FIG. 1. – Challenges of Construction

and consequently in this paper. First, the focus is primarily on basic research as defined in the context of construction. This differs from, but is complementary to, earlier efforts (2,3.4.6.7,8,9.10). The workshop's purpose was not to assess general and applied research and development in construction. The latter, of course, does account for the vast majority of the research carried out in this field. Second, within construction engineering and management in general, emphasis was primarily upon management, assuming that it is indeed possible to separate the two. Finally, the basic research topics identified subsequently are drawn primarily from the aforementioned workshop. For example, it was well beyond the scope of this effort to attempt a comprehensive survey of construction organizations.

Since the participants were deliberately selected for their stature and experience, it is believed that a reasonably accurate and balanced understanding of the industry's main problems did evolve. Nevertheless, one can by no means guarantee that the findings of the workshop precisely reflect the needs of construction as a whole. Indeed, since there was deliberately no attempt to reach concensus within the workshop, the render must not assume that this paper will necessarily represent the individual position of any one of the workshop's participants.

BASIC RESEARCH NEEDS IN CONSTRUCTION MANAGEMENT

This section summarizes potential areas for basic research in four main categories: (1) Manpower and organizational development: (2) management methodologies: (3) innovations in construction methods: and (4) construction industry dynamics. The interested reader can find more detail on all of these in the workshop's research report (5).

Manpower and Organizational Development. – The present economy notwithstanding, it appears certain that some of the most critical problems in many sectors of construction are. (1) A future shortage of skilled technical ill1l1 managerial talent: and (2) effective employment of the human resources that ore available. Especially on large projects, many companies are finding that existing organizational structures cannot adequately cope with growing needs. Increasing governmental requirements are further complicating this situation. One full session was therefore devoted to topics within this field. General areas examined included human and organizational development the interplay of design and construction, and the evaluation of management productivity. Specific research needs identified or implied within the workshop are summarized in Table l.

Of the topics in Table I, there was a general impression that some of the most difficult problems are: (1) To improve selection and development of managers who can be both comfortable and capable in running "super-projects": and (2) to develop organizational structures that can most effectively cope with such projects. These views, of course, were somewhat influenced by the large-project backgrounds of several participants. Nevertheless, in terms of both needs and potential impact, this area deserves a high priority for basic research efforts.

Management Methodologies. – Much academic research to date in construction has been devoted to new and improved analytical tools and administrative aids for management, but the results have often been subject to question and controversy. Subjects of interest herein include cost engineering, planning and scheduling, quality assurance, resource analysis, management information systems, productivity analysis, simulation, estimating, etc. The workshop's session in this area served to identify fundamental problems in need of work and to suggest ways that related research could be made more meaningful. Table 2 summarizes some of the major basic research needs that were either explicitly or implicitly stated in the workshop.

Topics in Table '2 that might be considered for highest priority include: (I) Bring analytical methods, information systems and control tools closer to the managers who need them (or decision making. i.e., adapt the technology to fit management, not the other way around: (2) reduce the "care and feeding" required to implement such systems while making the models themselves more realistic and adaptable to actual project conditions; (3) develop better methods for "problem forecasting," with provisions for analyzing risk and uncertainty: and (4) improve means of communications at the design-construction interface.

TABLE 1. – Research Needs in Manpower and Organizational Development

Category (1)	Problem sources (2)	Research areas (3)
Management personnel	Super projects – Super projects, often lasting decades and costing over $1 billion, have stretched managers too far. They "burn out," suffer "combat fatigue." and boggle at the enormity of decisions. Long project durations – The duration of large projects make it difficult for potential managers to obtain well-rounded experience.	Selection – Identify qualities that determine which managers can endure on large projects and make sound decisions. Training – What basic skills are most important? What special training can develop the de-sired abilities? How can the training and development be accelerated? What is the potential for simulation with management games and case studies" What is "management development?" Analysis – Make comparative studies of management styles, characteristics and effectiveness. Study cause-effect relationships: What is and is not relevant in enabling managers to accomplish objectives". Evaluation – Determine how to objectively evaluate and compare productivity and efficiency of managers and alternative management approaches.
Organizational development	Structure – Project-type organization with typica1 matrix organization problems Project life cycle – Temporary organization with rapid growth, intense activity, limited resources, and phase-out Repetition and duplication – lack of effective transfer of knowledge and experience from one project organization to another External constraints – Project organizations have difficulty responding to outside groups – environmental, regulatory agencies, etc. – that affect construction.	Building project teams – Behavioral science concepts applied to improving communications and motivation in project environment Consider in the context of temporary team building. Study working relationship within interdisciplinary prospect teams. Structure versus project size – Analysis of necessary changes in characteristics and requirements of organizational structure with changes in size of company or of project. Documentation and transfer of knowledge – Develop more effective means to document knowledge, experience, methods, successes, and failures from previous projects so that they can be effectively transferred to new projects to minimize reinvention of procedures and repetition of mistakes. External interaction – Deter-mine how projects could be bet-

(1)	(2)	(3)
Interplay of design, construction, and owner	Communications – Regardless of contractual approach, there continue to be communication barriers between engineering design and field construction. Objective - There are different time-cost tradeoff for the owner, architect/engineer, contractors, etc., that produce different goals for each.	ter organized to interact effectively with the external organizations New training requirements – Improve the breadth of specialized training to enable engineers and others to function effectively at the design-construction interface. Interplay of design and construction – Study the owner-designer-constructor interplay for means to improve communication and understanding.

Innovations in Construction Methods. – Most new construction methods have been developed to solve immediate and pressing problems. This session in the workshop explored whether it would be appropriate to carry out basic research in anticipation of problems that may still be well into the future. A possible example might be prefabrication and standardization to accelerate construction of projects designed to implement new energy technologies. The session focused not so much on specific technical problems that need solving, as on identifying broad areas and on exploring the relationship of universities and industry in carrying nut research. The results ore summarize in Table 1

Subjects within Table 3 viewed as having higher priority include: (1) Develop integrated approaches to design and construction, with increased use of multipurpose components and subsystems, less total components, reduced incompatibility, and less field labor; and (2) develop rational efficient function-oriented standards that will aid automation, mass production, and industrialization in construction.

Construction Industry Dynamics. – The final session was devoted to examining the construction industry from a national perspective. Questions here included: What are the underlying relationships of construction to the U.S. economy? What are the primary interactions? What secondary impacts do major construction policy decisions – or individual project decisions – have on other areas of the economy? How can the resources of construction hest be used'? Is there a need for a coordinated national construction policy?

It has been said that the construction industry, as a whole, cannot significantly influence the demand for its services. or control the supply. In contrast to industries such as automobiles and railroads, construction is not in a position to accumulate capital. It is largely a service industry. How, then, could the industry be more effective in controlling, or at least influencing, its own supply and demand?

As an example, in early 1974 there seemed to be an insatiable need for more nuclear projects, and the industry was hard-pressed to fill it, Six months later, largely as a result of short-run financial problems in the utilities industries.

Category (1)	Problem sources (2)	Research areas (3)
Utilization of metals and information	Demand on users – At present, sophisticated, analytical models and management information systems designed by technical people often seem to be designed primarily for such people. In reality, there is often a large “temperament gap” between model builders and managers. The technology needs to he adapted to fit the managers other than hoping for the reverse to happen. Data inundation – In both volume and content, managers often have difficulty absorbing let alone applying information provided by analytical models and systems.	Communication barriers –Break down communication barriers between managers and analytical systems Study the interface between them: develop means for more direct and effective interaction: permit query, sensitivity analysis and insertion of managerial judgment. In electronic forms this means computers must be used in more innovative ways to communicate directly with non-technical human beings. Temperament gap – Identify characteristics of "analytical" and "managerial" people. This understanding could help bridge the so-called "temperament gap" between the two and help build teams capitalizing on the real strengths of each. Problem solving – By applying “management by exception." good systems have over-come many problems of data inundation. Identification of problems, however, is only a relatively passive first step. Re-search must progress to dynamic manager-system interaction for solutions to problems once identified.
System development	Operational workability – Existing systems require excessive “care and feeding" relative to benefits obtained Data required for maintenance and updating is often voluminous and cumbersome. Oversimplification of reality – Oversimplification may limit casting models to artificial situations and thus discredit them in broader applications blare of the richness of real life is needed in model building. Duplication and repetition – Development and implementation of methods for scheduling, cost control, etc., have seen considerable reinvention. There is little standardization.	Dispensing with data – Make existing systems more workable. Integrated systems can reduce duplication of data entry. It is possible in many cares to dispense with data altogether and instead derive it on demand through proven models and known operators. Realistic modeling – Integration of analytical models and information systems could better recognize complex interdependencies in projects. Further research would provide systems which vary in complexity and sophistication depending on the size and complexity of projects. Coordinated development efforts – The MIT research that

Table 2. - Continued

(1)	(2)	(3)
	Quality endurance – Quality assurance requires tremendous amount of field and office labor. Another problem is mutually acceptable incentives for contractors to provide quality products at reasonable cost	led to standard civil engineering programs such as STRESS, STRUDL, and COGO could benefit construction in areas such as project scheduling, cost control, estimating, and quality assurance. Industry-wide efforts could reduce the duplication and repetition inherent in independent development. Research in quality assurance and inspection – How can quality assurance procedures become more standardized and reliable? To what extent can such procedures be programmed and handled by computer? There is especially a need for simplified and more accurate testing and inspection appropriate to "performance specification."
Forecasting and decision making	Problem forecasting – Many systems point out problems after the fact, or just make linear projections of trends Information is needed in time for corrective action, Functional integration – With date bases and integrated systems, diverse specialties are more closely interwoven This creates problems hut also have potential advantages. Risk and uncertainty – There is insufficient evaluation of actual hazards or steps to minimize them, especially in hostile environments and prospects starting construction without detailed plans	Forecasting – Research could investigate improved methods for projecting costs, cash flows, inflation, manpower productivity, resource demands, schedules, and quality results, including the analysis of risk and uncertainty mentioned as follows. Influence of technology on organization – Determine how data bases and integrated management information systems effect the ways people work together. This. in turn, could lead to ways to restructure construction project organizations to lake hest advantage of new technology. Analysis of risk and uncertainty – Investigate improved methods to analyze risk quantify uncertainty, consider alternative strategies, and make decisions. This, in turn, could improve forecasting techniques for methods decisions and cost estimating.
Communications	Design-construction interface – As construction becomes more complex, traditional orthographic drawings and written specifications create problems	Improved design-construction communications – Investigate new technology and alternative media for communicating between design and construction.

TABLE 2. - Continued

(1)	(2)	(3)
	in communicating designers' intentions to constructors, and in designers' understanding of field construction. On-site communications – On large projects it is especially difficult for management to monitor all operations in progress.	Some projects already make extensive use of physical models; this could be expanded. Computer graphics and other manipulable visual displays could add another dimension. Computers could also assist more in presenting technical specifications. Improving on-site communications – Visual communications give management a better feel for the project and more confidence in decision making. Possibilities in this area include more innovative use of closed circuit TV and time-lapse cameras as management tools.

there were postponements and cancellations of projects, and pending payoffs of the skilled people the industry was so recently struggling to find. What are the long-run consequences of these decisions for the construction industry and for the U.S. economy?

Topics considered in this session may lead to research in economic modeling, long-range forecasting, environmental impact policies, long-term goal definition, developmen1 of an industry profile, etc. Table 4 gives an overview of some of the long-term research needs in these areas.

Of the topics in Table 4, the following may be viewed as having higher priority: (1) Develop a better understanding of the relationship of construction to society, to government, and to the economy; (2) explore how to moderate instability of demand for construction services, and temper the consequent effects on the industry: and (3) improve cooperation for research within the industry, and between the industry and universities.

IMPLEMENTATION

Two major requirements for implementation of basic research efforts in construction project management are: (1) Individuals and institutions with the resources, experience, interest, and capabilities to carry out such research; and (2) the incentives and means to provide funding. This section will examine each of these in turn.

University Education and Research in Construction. – Since World War II, and especially in the last decade, numerous college and university programs have evolved that are aimed primarily at the construction industry. Suddenly, the construction process and its management – the logical culmination of the conceptual and design phases – has been recognized for what it is: An integral part of the total engineering and management process required to provide new facilities. There are now dozens of 4-yr undergraduate programs: many are divisions within

TABLE 3. – Research for Innovations in Construction Methods

Category (1)	Problem sources (2)	Research areas (3)
Design-construction interplay	Uncoordinated suboptimized components – Today components and materials for structures, including framing members, HVAC, plumbing, electrical, etc., are produced by many separate industries, but with little overall coordination and few multiple-purpose components. There is need for fewer total components and especially fewer on-site-assembled components. Inefficient standards – Many standards are suboptimized by system and are often set by the industries that manufacture the components. Also, specifications by architect/engineers are sometimes unnecessarily high for actual requirements. Energy factors – Energy shortages create problems in diverse situations like designing for improved HVAC efficiency, minimizing fuel needs in earth-moving and analyzing total energy requirements from raw material through life of facility. Space restrictions – In conventional structures, land costs and other factors are putting space at a premium. These problems are even more acute for structures in hostile environments, portable structures, etc. New situations – There is need for more rapidly adapting design and construction to new environments and new technologies, such as ocean construction.	Integrated design – Integrated design could make increased use of multi-purpose components and subsystems, reduce the number of physical elements in structures, reduce costly on-site labor, and hence reduce costs. Perhaps even more important are evaluation of the overall life-cycle costs of facilities. Rational standards and industrialization – Impartial research is needed for lighting standards, optimum room temperature, de- sired fire resistance. etc. There is need for new ways to express precise yet realistic specifications that communicate to designers, owners, contractors, craftsmen, users, and vendors. Energy Research – Development of energy-related guide- lines for design of systems, selection of materials and components, and construction methods would assist designers and constructors in this area. More fundamentally, how should changing energy economics affect traditional approach towards design and construction." Miniaturization – Determine ways of reducing the size of support service facilities such as utilities, HVAC, etc. Study how much space is really needed by users and determine ways to utilize space more efficiently while not detracting from its function. Adaptation – Determine how research can he incorporated into new situations to accelerate the evolution of efficient solutions.
Materials and components	Testing – There is need for accelerated test methods for long-life but failure-prone materials such as paint, joint sealer, roofing systems, etc. This also applies to obtaining shorter	Automated testing – Develop methods to accelerate tempting and make results more reliable: e.g., means for reliable testing concrete in the plastic state could provide quick feedback.

Table 3. – Continued

(1)	(2)	(3)
	feedback on production-critical items such as concrete strength, welding, and weld testing. Better solutions – Lighter, stronger, more durable materials are needed as design capabilities advance. Also needed are improved field capabilities for handling, and for obtaining and verifying specified quality. Approval of new materials – There are problems in getting new techniques and materials approved with respect to safety building codes, etc. Excessive field labor – Many methods and materials are developed with little regard for the amount of labor required for on-site fabrication installation. This applies to old methods too. "We still lay bricks one at a time." Waterproofing – Problems are common in making structures waterproof, especially basements. Roofs, etc.	Computerized weld-testing needs investigation. Reliable predictions of long-term performance on the basis of short-term changes under accelerated lab testing. New research in materials – Considerable work is now underway in composites of concrete, fibers and polymers for producing durable, high-strength concrete. More can be done on this and similar approaches could be taken to other elements. Accelerated approvals – Re-search could investigate both organizational and testing aspects of accelerating the approval of new materials and components for construction. Automation and mass production – Develop ways to apply automation and mass production in the more labor-intensive aspects of construction, such as installing electric wiring. Examine prefabrication, both on-site and off-site. Improved waterproofing – Investigate both improved materials and construction procedures for waterproofing.
Equipment and technologies	New tools – There is continuing need for improved equipment for applications such as open sea dredges capable of structural excavation with wider tolerance for swells: excavation and materials disposal under-ground: welding high-strength steels; laying large-diameter pipe in the open sea: concrete handling; and excavation. Productivity and efficiency – Even the best equipment has wide variations in productivity depending on the operator's skill and working environment.	New and improved equipment – Investigate equipment for operations in hostile environments, such as the arctic, under sea, and near the equator. Others could explore new applications of technologies such as compressed air for production (erecting structures. transport, excavation. etc.), mobile factories for field manufacture, etc. Automation – Miniaturized computers and logic have potential for anything from fuel-metering and gear-shifting to providing an equipment-control interface for field implementation of simulation. Automated equipment could remain productive in bad weather or even

TABLE 3. – Continued

(1)	(2)	(3)
Construction procedures	Investigation and exploration – Better means are needed of predicting material to he excavated and supported in tunnels, shafts, chambers and deep foundations. Start-up – Improved techniques are needed for starting projects in remote locations – bootstrap operations. Lack of innovation on projects – Often people doing work know of better way it could be done, but are reluctant to suggest their ideas.	in areas hazardous to human life. Improved geologic investigation – Improve means of determining properties of materially to he excavated: evaluate their implications for construction. Start-Up – Study successful methods used for establishing construction projects in remote locations, identify the elements of success, then document these in a form useful for other projects. Motivating innovation – How can management create an "innovative atmosphere" on projects and within the industry? How can people with knowledge for improving the tasks become involved in improvements as well as performance'? What are the characteristics and key elements on projects where innovation is prevalent."

architecture, civil engineering, or architectural engineering. There are also handful of graduate education and research programs, most are small, having anywhere from one to five full-time faculty. Of these, most are identified with engineering departments in some of the most distinguished universities in the United States and abroad. Research in graduate construction engineering and management programs is worth at least a brief review since this in turn may become an important source of basic research in construction.

Although most are still fairly new, established graduate programs hove already made significant progress in both research and education. Until a few decades ago, there was very little university research and no coherent body of college-level coursework aimed specifically at construction. Many innovations that are increasingly taken for granted in the industry today either originated in or acre considerably advanced through research efforts of these programs. Examples include time-lapse photography for operations analysis, computer simulation of field operations, behavioral science research into the workings of project management teams, computer-based information systems, studies of labor and industrial relations, and new methods and techniques for the planning, scheduling, and control of resources on projects.

On the education side, there are now many widely-accepted courses that make up the core curriculums of today's graduate and undergraduate programs. New courses continue to be introduced, and many of these will become standard subject matter in the future. There have now been literally thousands of graduates from the established construction programs. Many have gone on to become

TABLE 4. – Research in Construction Industry Dynamics

Category (1)	Problem sources (2)	Research areas (3)
Construction, the public, and government	Industry credibility – Many problems in construction's credibility with the public stem from much-publicized cost overruns and schedule delays on projects such as rapid transit systems, and to the disruptions that occur while work is in progress. Mutual perception – Problems with government, including perceived overregulation by EEO, OSHA, EPA, etc., largely stem from a lack of government understanding of construction; e.g., regulatory agencies may not realize their cumulative effects on the industry Use of construction in fiscal/ social policy – Construction is often placed on the forefront of government fiscal and social policy. Examples include money for home loans, using contractors to increase minorities in unions, etc.	Relationship to society – Assess how construction affects our way of life. This may enable the industry to more effectively cope with forces ad-verse to it. Determine how construction expertise can enter more into the evaluation of what and where services to the public should be developed. Interactions – investigate the relationship of construction to government, study the interaction between the industry and government agencies, and develop good information with which to educate all parties concerned for their decision making and action. Interrelationships – Study interrelationships of politics, legislation, industry, owners and the public. Determine more direct ways to meet industry and national objectives.
Construction and the economy	Demand instability – Instability of demand dominates everything in construction. Seasonality is chronic. Construction has an amplified reaction to basic business and economic cycles. Many economic problems in construction relate to the lack of mobility of resources, especially labor. Often there is too much work in some regions at the same time that others are suffering localized recessions. There is a need for a more continuous workload, for market forecasting, and for improved projections of future trends by type, area and volume. Finance – Problems recur in funding both large and small projects. Government competition for finite funds exaggerates these problems. Related problems are in predicting escalation, and incorporating it into equitable contracts.	Economic modeling – What factors in the economy have the greatest impact on construction, and vice versa? Identify the predicators, then model, then try to influence. Coordinate existing models. What are the industry's capacities for production today? Assess its adaptability to short-run and long-run demand changes. Determine how to forecast resource capacity versus backlog. What is the post-industrial economy going to require in construction ser-vices? Evaluating costs – Determine procedures for identifying the elements in cost overruns. i.e., the portions attributable to inflation versus change of scope versus inefficiencies. Develop ways to internalize and quantify external costs, such as OSHA, EPA, etc.
Construction industry organization	Structure – In general, there is a perceived need for a corn-	Restructuring – If the industry were to be restructured.

TABLE 4. – CONTINUED

(1)	(2)	(3)
	piete restructuring of the industry to reduce "layering, permit an integrated approach to objectives, and permit more standardization. Contractual relationships – Some fear that noncompetitive contracts may reduce incentives for efficiencies in construction, slow innovation, cause more inflation, etc. Research cooperation – There is a lack of desire to share re-search with competitors. Therefore an impartial means for sharing is needed. Similarly, there is a need for closer cooperation between university and industry people working in construction.	what objectives ought to guide this effort? What new relationships would be needed? What new institutions and procedures'? Would the benefits outweigh the costs? Contractual relationships – What are the long-run influences of different forms of contracts on efficiency, innovation, Inflation, etc. Improved cooperation in re-search – Explore possibilities for a "clearinghouse" organization for disseminating construction research. Study the close relationships between universities and industry in Northern Europe to find ideas that might promote closer cooperation in the United States.

managers on some of today's most challenging and successful projects. Others have advanced to the top executive ranks of some of the largest and most reputable companies, and of many smaller but innovative companies as well. Still others are found in government construction agencies, large private consumers of construction services, and as faculty in construction programs in other universities.

It is especially important to recognize the indirect impact that university research has by its close relationship to the educational process. Of course, it is good when a given research effort directly contributes to solving an existing problem. But in the long run, university research can have a greater impact through two influences it has on students. First, while research is in progress, student assistants have the opportunity to sharpen their minds and immediately apply their learning doing research. Second, results of successful research efforts often find their way into courses that will be taken by other students, perhaps a decade or more in the future, who. in turn. will apply this new body of knowledge in their own careers. Universities are thus not only charged with developing new knowledge through research, but of passing that knowledge on to succeeding generations through education. It is in this interplay between research and education that universities can have their greatest impact. This should apply equally well to basic research in construction.

Incentives for Funding. – As mentioned earlier, the fragmented intensely competitive nature of construction makes it difficult to undertake industry-wide programmatic efforts such as a significant venture into basic research. Furthermore, construction is primarily a service industry and thus does not accumulate significant amounts of capital when compared to industries such as steel, transportation, and minerals. Thus, if a firm cannot preserve the fruits of its research innovations in the form of new processes or more efficient capital facilities, it has less incentive to invest in research. For these and other reasons, it is unlikely that the construction industry itself could invest in basic research on the scale found in capital-and-technology-intensive industries.

Nevertheless, there are major financial incentives for investing not only in applied research in construction, but in basic research. These days one too often hears of large projects with cost escalation measured not just in millions of dollars, but in billions. The cumulative effect of cost escalations on smaller projects is undoubtedly even greater. American ingenuity and know-how is still effectively coping with most technological problems in construction, but management and administration is too frequently inadequate on larger and more complex projects. If investments in research could overcome some of these difficulties and begin to pare down these billion-dollar cost increases, someone ought of benefit. In the workshop, the participants from the consumers of construction services, in both government and private industry, were generally the first to point out that it is their organizations that ultimately should be willing to make such investments, since they and their customers will be the primary beneficiaries. Once recognized, however, there is still a quantum leap to be taken to develop effective institutions to support such research in a coordinated and productive fashion.

RECOMMENDATIONS AND CONCLUSIONS

This paper and the workshop upon which it was based were designed to identify, set priorities for, and focus high-level attention on the need for basic research in construction engineering and management. There is now and will increasingly he a need to bring research talents and capabilities both within and beyond the academic community to bear on performing basic research leading to means to solve problems in construction. A second important purpose of the workshop was to bring about closer working relationships between the construction industry, consumers of construction services, and university pro-grams in construction engineering and management.

Earlier sections of this paper had several topical recommendations. General policy recommendations are as follows:

1. Universities and related research institutions should recognize construction and the management of construction projects as important areas of endeavor in which research can make major contributions.
2. The construction industry should focus attention upon the importance of basic research to its own long-run well-being and that of its clients. It should thus support and encourage the establishment of organized research programs, and play an active role in such programs once they are established.
3. As the primary economic beneficiaries of improved methods and management in construction, and as the organizations with the necessary capital and resources, both public and private consumers of construction services should actively encourage the development of research programs in construction and should provide the major funding to enable such efforts to grow.

It is inevitable that many readers will take issue with both major and minor points in this paper. 1ndeed, this paper will have failed if it does not bring forth other points of view. Its underlying purpose has been to provide "raw material" that can serve as a focal point for analysis, criticism, and suggestions which, in turn, will provide a useful background for consideration and decision making.

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APPENDIX I. REFERENCES

1. Bush, V., "Science – The Endless Frontier: A Report to the President." U.S. Government Printing Office, Washington. D.C., July, 1945.
2. "Construction Engineering and Management Research." *Report of Engineering Foundation Research Conference*. University School. Milwaukee. Wise., Engineering Foundation, Ne'er York. N.Y., July 17-21. 1967.
3. Hutcheon. N. B., "Research for Construction." *Special Technical Publication No. 2*. Division of Building Research. National Research Council. Ottawa. Canada. Mar., 1974.
4. "Outline of Research Requirements for Construction," Report by the Committee on Research, W. F. Burkart, Chmn.. *Journal of the Construction Division*, Vol. 94. No. CO2, Proc. Paper 6189, Oct., 1968, pp. 233-244.
5. Paulson, B. C., *Goals for Basic Research in Construction*. Department of Civil Engineering. Stanford University, Stanford. Calif., July, 1975.
6. "Probing the Future," *Engineering News-Record*. Centennial Issue, Vol. 192. No. 18, April 30. 1974.
7. "Research Needs in Civil Engineering Relevant to the Goals of Society." Colorado State University and the American Society of Civil Engineers. Fort Collin., Colo., June, l971. pp. 246-250.
8. Rossow, J. K.. and Moavenzadah. F., *The Construction Industry: A Review of the Major Issues Facing the Industry in the United States*. Department of Civil Engineering. Massachusetts Institute of Technology. Cambridge. Mass.. Summer. 1974.
9. Shaffer. L. R., *Research in Construction Management: Its impact on the Industry*. Department of Civil Engineering. North Carolina State University, Raleigh, N.C., Jan.. 1974.
10. Taylor, D. C., "Report on a Program Plan form Experimental R&D Incentives Program in the Construction Industry." ASCE Research Incentives Program. New York. N.Y., July. 1974.