The Business Roundtable

CONSTRUCTION TECHNOLOGY
NEEDS AND PRIORITIES

A CONSTRUCTION INDUSTRY
COST EFFECTIVENESS PROJECT REPORT

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CONSTRUCTION TECHNOLOGY NEEDS AND PRIORITIES

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I

SUMMARY

There are myriad needs for improvements, small and large, in construction technology. This study focuses on 1 7 types of problems, solutions to which would help to reduce the cost of erecting commercial buildings, light-industrial projects, heavy-industrial projects, and power plants. The list was compiled from 128 responses to a questionnaire survey mailed to selected owners, contractors and designers. Items that deserve priority attention in technological efforts were identified through lengthy interviews with 51 craft superintendents and field engineers at 14 major job sites across the U.S.

The survey showed considerable differences in the kind and cost of the work involved in the four sectors of construction that were studied. Among the projects surveyed, the average cost ranged from $25 million for a building to $190 million for a heavy industrial facility and $470 million for a power plant. Even so, considering cost, complexity and time required for installation, the study finds that three areas of construction have the highest potential for gains from technological research: piping, electrical work, and installation of mechanical equipment.

Piping appears to be the most inefficient of all the major areas of physical construction. Alignment is often difficult and time-consuming because of close tolerances required. Tools often have to be made on the job site for alignment of large diameter pipe. Flexible pipe and especially flexible bends would help.

Installing mechanical equipment – a large item in heavy-industrial projects and power plants – involves complex difficulties in alignment and leveling. Tolerances are sometimes as fine as one three thousandths of an inch. Needed are better alignment tools, perhaps equipped with lasers and microchip computers.

In electrical work, installing raceways and testing are identified as the most complex and awkward activities, partly because the raceways must be put in place at a time when numerous craftsmen from other trades are vying for the same space. Flexible conduit would solve some of these problems, and plug-in connectors would also help.

If relatively inefficient piping installation could be made as efficient as the average of all other operations through technological innovation, the cost savings would be impressive: an estimated $5 million per typical project in the power industry alone.

II

BACKGROUND

The construction industry has traditionally lagged behind other industries in technological improvements. Since each project occupies a unique piece of land, construction techniques need to be flexible. So, big projects have traditionally used more labor instead of automated methods and procedures. Construction companies have not considered money spent on research to be cost-effective. Today there is even a scarcity of data about the needs and opportunities for better technology in construction.

Pressures are increasing to make construction projects more efficient. An obvious area for major cost savings lies in technological advances which can have both immediate and long-range benefits.

Very little information has been published regarding construction research needs. The Associated General Contractors of America, through its Education and Research Foundation, mailed questionnaires to 1,200 contractor members in 1975 to assess research needs in the construction industry and to identify appropriate procedures for starting research. There were very few responses.

III

HOW THE STUDY WAS MADE

To identify areas of technological need and potential for progress, a new questionnaire survey was mailed to selected owners, contractors and designers. A total of 128 surveys were returned with responses from 36 of the 53 companies invited to participate. Corporate level managers were asked to complete the questionnaire since they were felt to have a broad range of experience and still be familiar with recent projects. For large companies, individuals from different divisions were asked to respond. Thus, several questionnaires were returned from some firms, although no more than one response was received from each division. The surveys covered four categories of construction: 1) buildings, 2) light industrial, 3) heavy industrial, 4) power plants.

The surveys provided data on project size and characteristics, as well as information regarding craft make-up of the work force and distribution of costs among 17 construction areas. The survey was limited in scope and depth. It was focused on multi-disciplined projects complex enough to involve a variety of crafts and activities. It involved a limited number of companies and sites because of time constraints. A copy of a page from the survey is shown in Figure 1.

Respondents were asked to rate, on a basis of 1 to 10 (the low figure representing the least difficulty, etc), 15 separate indicators of inefficiency or construction difficulty on typical projects. The indicators ranged from “difficulty in estimating costs”, and “sensitivity to timeliness and quality of design” to “dependence on foreman competence’ and “sensitivity to prefabrication tolerances and accuracy

A basic assumption inherent to the questionnaire is that construction areas with high indicator ratings have significant opportunities for technological improvement. However, some areas may be inefficient, but represent only a small portion of a project, whereas other areas may be more efficient but represent a large portion of a project. To incorporate both factors, the indicator ratings were multiplied by the weighted percentages of project cost which they represented in each of the four categories of construction.

Next came interviews with 51 craft superintendents and field engineers at 14 job sites in the southwest, midwest and west, and in the mid-atlantic states. These were intended to pinpoint inefficient construction activities and opportunities for improvement.

Those interviewed rank-ordered the steps in erection procedures for each area of construction, considering complexity, skills required, and dependence on technical information. They also were asked to estimate the percentage of time required for each step in erection.

CONSTRUCTION TECHNOLOGY SURVEY

5. The following question is intended to provide insight into opportunities for technological improvement. Use your past experience on projects as a basis for answering each question. After each question, consider the civil, mechanical, and other categories listed, and rate each category on a scale of 1-10 with the following meanings:

   10—causes problems: a matter of concern: a priority area for technological improvement.

   1—a relatively stable area: not an obvious area for technological improvement.

   Leave blank any area which does not apply to your typical project.

Rate the work categories in terms of:	CIVIL					MECHANICAL						OTHERS					
	Earthwork	Foundations	Structure	Enclosure Skin	Interior Finishes	Roofing	Piping	Plumbing	Vessels	HVAC	Mechanical Equipment	Special Equip. Installation	Electrical	Instrumentation	Insulation	Coatings and Painting	Fireproofing/Protection
a. DIFFICULTY IN ESTIMATING COSTS																	
b. SENSITIVITY TO TIMELINESS & QUALITY OF DESIGN																	
c. NECESSARY LEAD TIME FOR SCHEDULING																	
d. PROBLEMS IN OBTAINING PROPER MATERIALS (CONSTRUCTION EFFORT—NOT DESIGN)																	
e. UNPLANNED REWORK ON YOUR TYPICAL PROJECTS																	
f. WHICH REQUIRES THE MOST COMMUNICATIONS BETWEEN ENGINEERING & CONSTRUCTION TEAMS																	
g. PROBLEMS IN MATERIALS HANDLING & DISTRIBUTION																	
h. SENSITIVITY TO PREFABRICATION TOLERANCES AND ACCURACY																	
i. NUMBER OF DIFFERENT CRAFTS REQUIRED																	
j. DEPENDENCE ON FOREMEN COMPETENCE																	
k. CRAFTSMAN SKILL NEEDED TO PERFORM OPERATION																	
l. REQUIRED SPECIALIZED TOOLS & EQUIPMENT FOR CONSTRUCTION																	
m. NECESSARY COORDINATION WITH SUPPORT CRAFTS (SCAFFOLDING, WELDING, TESTING, ETC.)																	
n. MOST WASTED TIME AMONG CRAFTSMEN																	
o. WASTED TIME WAITING FOR INSPECTIONS																	

FIGURE 1. QUESTION FOR PRIORITY RATING OF INDICATORS
(Indicators are listed at left of table)

NOTE: The numbers 1-10 are relative ratings. Thus, the same number can be assigned to more than one item. Write the number selected in the appropriate box, whole numbers only.

IV

FINDINGS

A basic premise underlies the results of the questionnaire and its analysis: areas with high indicator ratings are those with significant potential for technological improvement. The average indicator ratings showed significant differences between different types of projects, as did the data for craft makeup and the distribution of construction costs.

The “indicators” were chosen for conciseness, ease of understanding and brevity of response. The indicators were focal points of technological improvement potential within the scope of the study.

Profile of Projects Surveyed

Craft make-ups for buildings and light industrial projects show relatively higher percentages for the civil crafts (e.g., foundations, structure, skin, roofing, etc.), whereas heavy industrial and power projects are more labor intensive in the mechanical and electrical crafts. The building projects are also less expensive than the other types of projects.

The distinctions are more significant in percentages of construction cost. Table 1 shows the cost distribution of the 17 construction areas in each of the four categories. The cost percentages refer to installation only, and do not include the cost of equipment or special items. Nonetheless, approximately 62% of the direct construction cost of buildings and 48% of the cost of the light-industrial projects relates to the civil sector, as compared to 24% for heavy industrial and 31% for power projects. In contrast, the heavy-industrial and power projects have high direct-cost percentages for mechanical, electrical and instrumentation activities.

TABLE 1
PROFILE OF PROJECTS SURVEYED

		Buildings	Light Ind.	Heavy Ind.	Power
	Surveys Returned	8	16	68	36
	Average project cost (millions)	$25	$120	$190	$470
	Average peak work force	300	600	900	1,600
	Labor shares by craft (%)				
	Boilermakers	1	1	2	11
	Carpenters	16	14	2	1
	Cement Finishers	7	4	2	1
	Electricians	11	10	18	15
	Equipment Operators	1	2	4	2
	Insulators	1	2	4	2
	Instrument	1	3	5	1
	Ironworkers	14	9	7	10
	Masons	4	6	1	1
	Millwrights	1	1	1	1
	Laborers/Helpers	17	14	10	13
	Painters	4	3	2	2
	Pipefitters	9	14	22	18
	Riggers	1	1	2	0
	Roofers	2	3	1	1
	Teamsters	1	3	2	2
	Welders	1	2	4	1
	Others	5	3	1	3
	Construction Cost Distribution (%)				
Civil	Earthwork	4.8	4.3	3.3	6.2
Civil	Foundations	3.3	7.2	7.5	10.4
Civil	Structure	26.9	17.2	8.2	9.7
Civil	Enclosure skin	15.2	7.0	1.7	1.8
Civil	Interior finishing	11.6	8.5	1.6	2.2
Civil	Roofing	2.1	3.9	1.1	0.8
Mechanica	Piping	3.4	11.6	23.9	16.1
Mechanica	Plumbing	2.2	3.7	1.5	1.4
Mechanica	Vessels	2.0	1.4	7.3	3.9
Mechanica	Heating, ventilation & air conditioning	6.5	8.4	2.3	2.9
Mechanica	Mechanical equipment	5.4	6.0	9.9	18.5
Other	Special equipment install.	1.4	5.7	3.0	5.3
Other	Electrical	8.5	11.3	15.0	14.1
Other	Instrumentation	1.6	2.1	6.4	2.9
Other	Insulation	0.8	0.9	3.8	1.6
Other	Coatings & painting	2.0	1.0	2.1	1.6
Other	Fireproofing	20	2.5	1.4	0.6

Areas of Opportunity for Technological Improvement

Because of the differences in the kind and cost of work involved, the opportunities for technological advances are somewhat different for buildings and light-industrial projects than they are for heavy-industrial and power-plant projects (see Figures 2-5). When the "adjusted indicator values" are combined with the cost proportions of projects, the following areas appear to offer the greatest opportunity for technological research in the four sectors of construction studied:

Buildings:	Structure Enclosure skin Interior finishes Electrical
Light Industrial:	Structure Piping Electrical
Heavy Industrial:	Piping Electrical Mechanical equipment
Power:	Piping Mechanical equipment Electrical

FIGURE 2. ADJUSTED INDICATORS — BUILDINGS

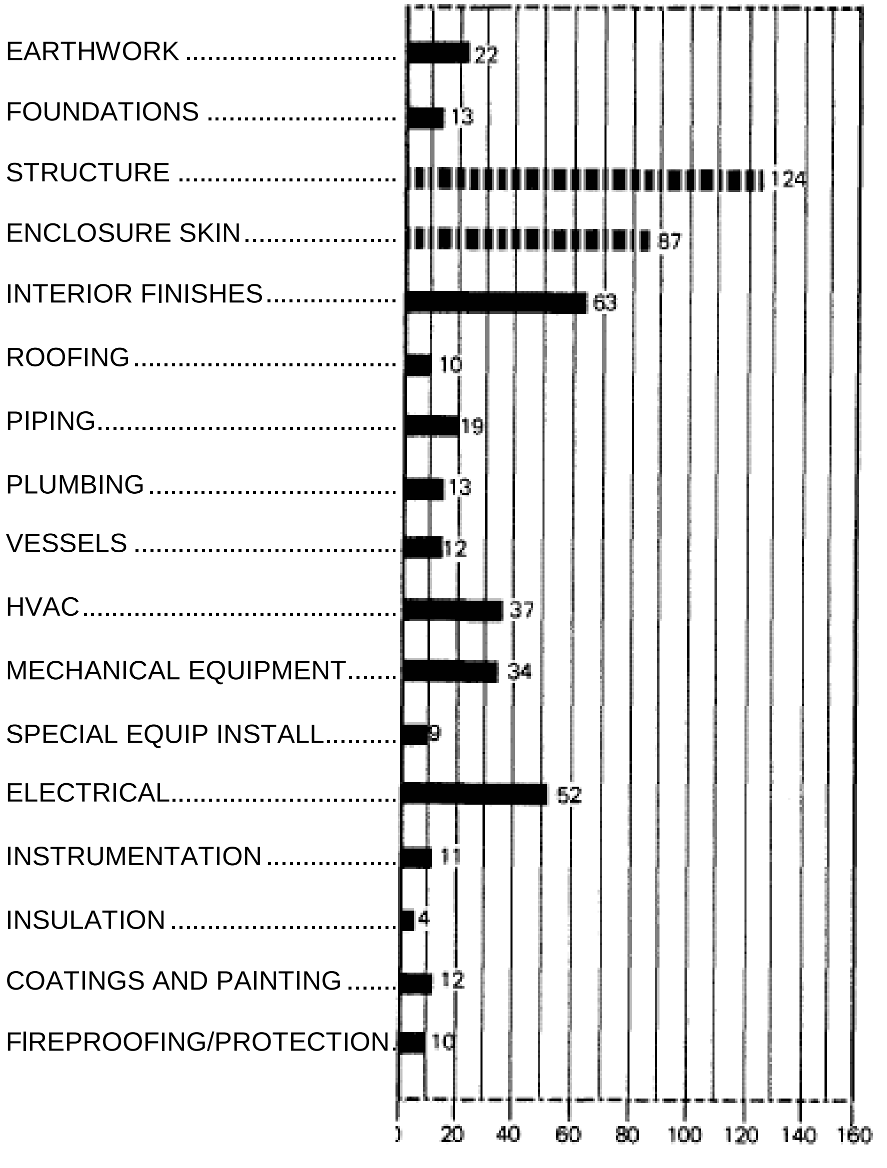


FIGURE 3. ADJUSTED INDICATORS — LIGHT INDUSTRIAL

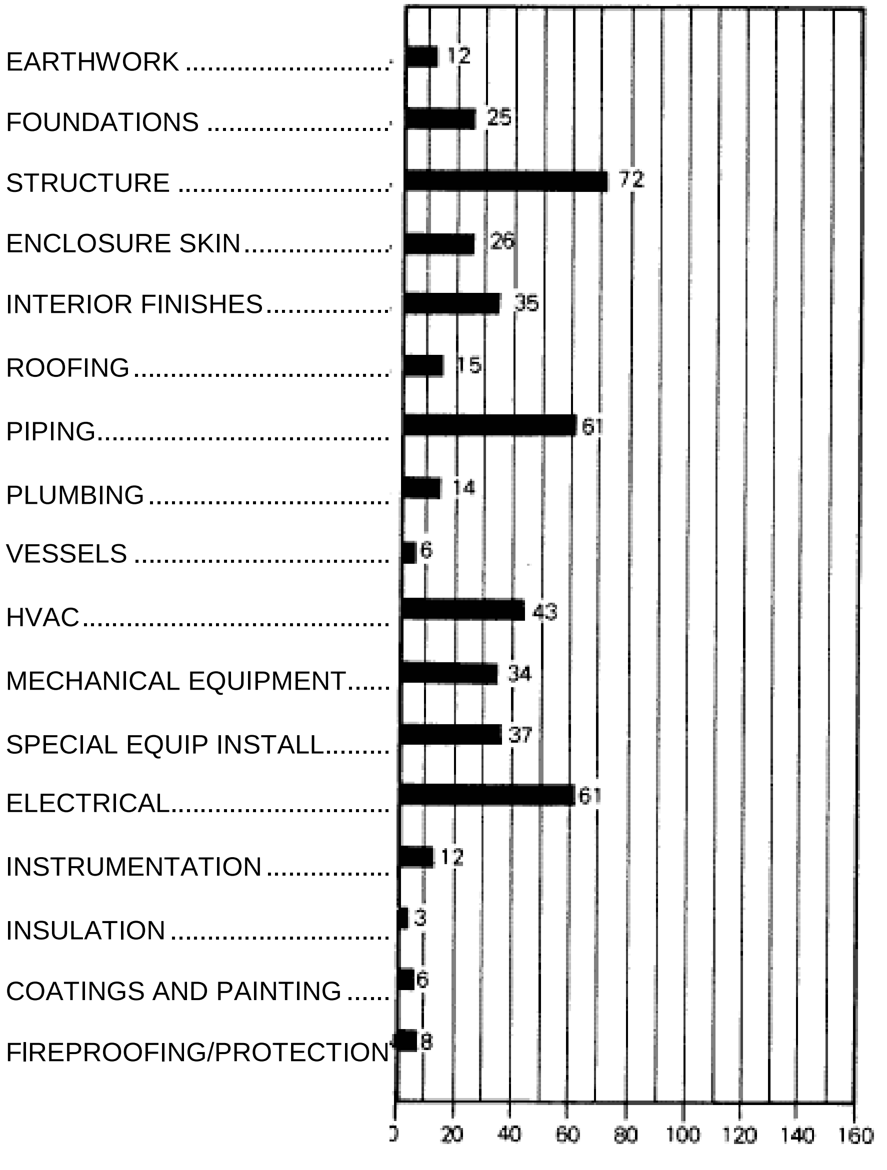


FIGURE 4. ADJUSTED INDICATORS — HEAVY INDUSTRIAL

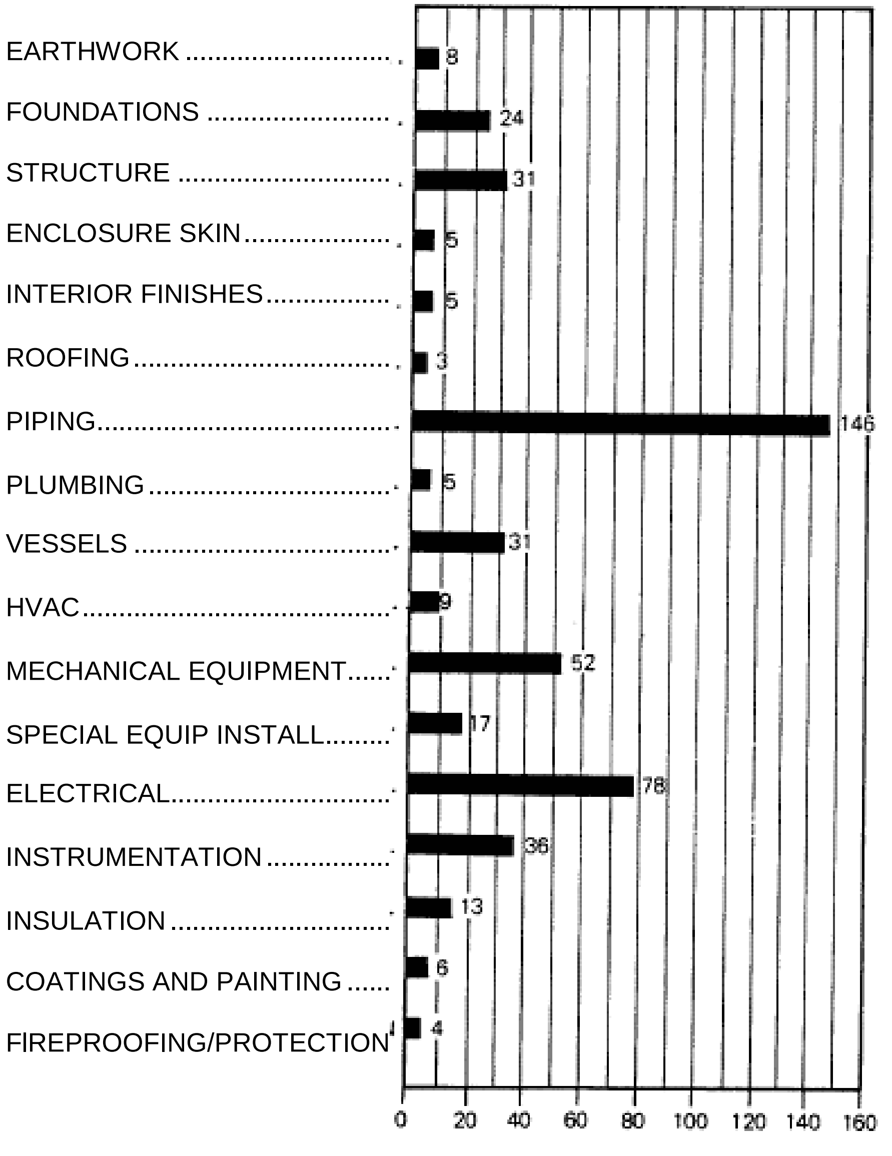
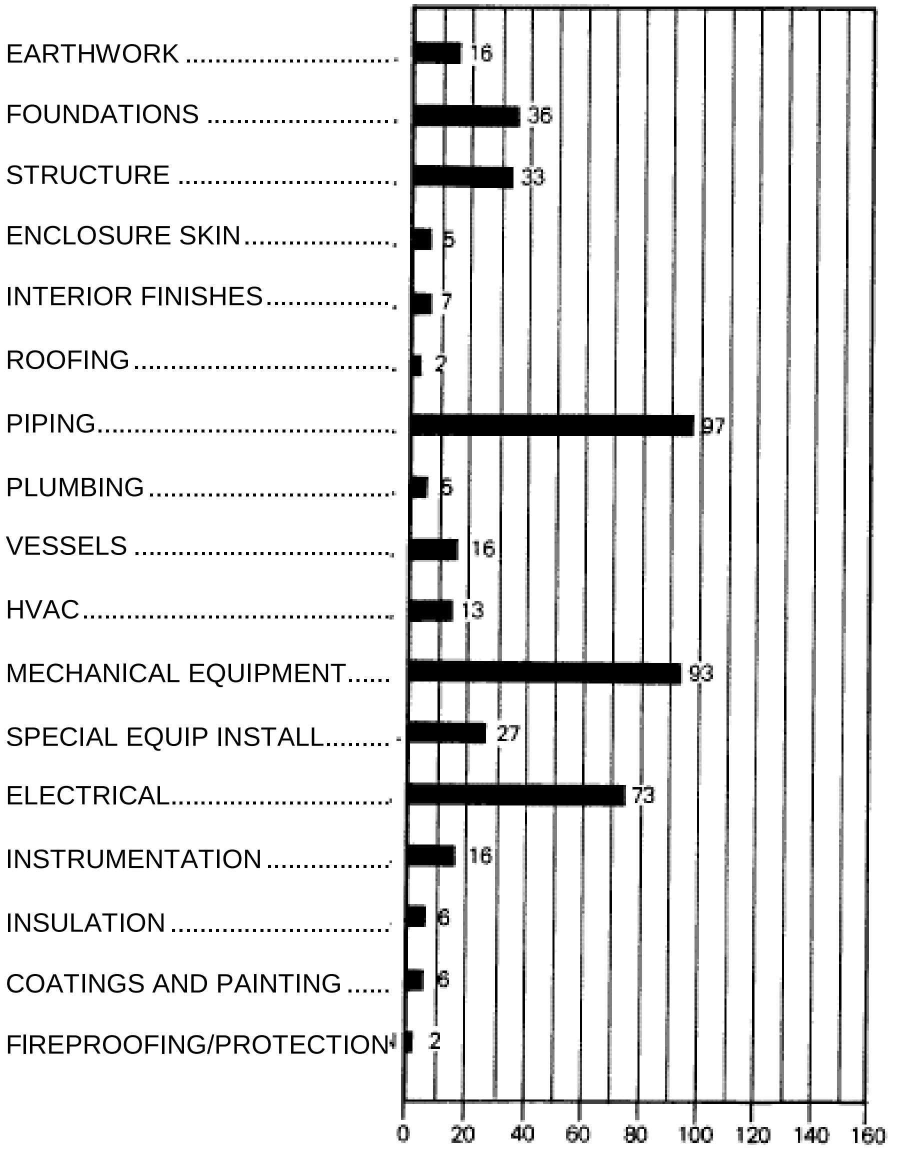


FIGURE 5. ADJUSTED INDICATORS — POWER



Other areas, although showing less potential, also offer significant opportunities for technological research.

The Industry-Wide Potential

Though technological needs vary among the four sectors of construction, there are also many similar needs, based upon the same criteria of indicator difficulties and proportion of project cost as shown the following table.

TABLE 2

INDUSTRY-WIDE AREAS FOR TECHNOLOGICAL RESEARCH

Areas of highest overall potential
Piping
Mechanical-equipment installation
Electrical

Areas of high overall potential
Structure
Vessels
Heating-ventilating-and-air-conditioning
Special-equipment installation
Instrumentation

Areas of medium overall potential
Foundations
Enclosure skin
Interior finishes
Earthwork

Areas of low overall potential
Roofing
Plumbing
Insulation
Coating and painting
Fireproofing and protection

Of the 17 areas considered for construction projects, three – piping, mechanical equipment installation, and electrical – appear to have the highest potential for technological advance. Five other areas –structure, vessels, instrumentation, installation of special equipment, and heating-ventilation & air conditioning – also ranked highly in all four construction sectors, according to both indicator difficulties and proportion of project cost.

Activities for Technology Priority

The six areas listed below were selected for more detailed investigation:

- Piping
- Mechanical and special equipment installation
- Electrical
- Instrumentation
- Concrete construction
- Steel construction

These areas correspond to all except two of the eight areas identified as those with high or highest potential in the questionnaire survey. Vessels and heating-ventilating-and-air-conditioning were not included: installation of mechanical and special equipment were combined. Structure was separated into concrete and steel construction because of distinct differences in the operations.

Typical Work Activities

By way of illustration, the following are some of the common steps associated with the three areas of highest overall potential.

Piping

Piping is the most inefficient of major construction tasks. A typical pipe installation involves these procedures:

1. Procurement
2. Transport materials to erection location
3. Lift pipe into place
4. Align pipe sections
5. Connect pipe sections
6. Inspect and test pipe and connections

Pipe sections may be either bolted or welded; the first connection may be temporary, until the next section is lifted into place, or final connections may be completed as each section is installed. Considered about equally complex or awkward are the tasks of ***alignment, connecting*** and ***lifting the pipe*** into place (erection). Alignment is one of the activities, along with connecting, which requires the greatest skill to perform and is considered, with lifting into place, highly dependent on technical information.

Pipe Alignment: Special tools for alignment are often used. On some sites, a plumb bob and level are still the standard alignment tools, but alignment clamps are becoming increasingly popular for all sizes of pipe. Large diameter pipe is a particular problem. Tools for its alignment often must be fabricated on the site. The major reason alignment is so difficult and time-consuming is the degree of close tolerance required. Flexible pipe would permit greater tolerances, as would flexible bends. Another useful development would be an inter-flange connection device that would allow slight alterations in the direction of a pipe. Another potential remedy for alignment problems would be to develop more accurate alignment equipment. Here laser technology is promising; it could even be used to align several sections of pipe at the same time.

Connections represent 25% of the total time for piping installation. Most of the problems involve welding. Considerable welding research has been conducted, but not all of the available technology is being used to its potential. Part of the inconvenience and costliness of welding stems from the bulkiness of welding equipment. Some piping superintendents contend that a crew of a welder and a pipefitter require an hour or more to dismantle their equipment and move it elsewhere to work. Many forms of welding use consumable electrodes, which means welders must often make extra trips to tool rooms for supplies. Shielding the weld arc from impurities in the atmosphere is a concern. Inspections and corrections are a problem. The application of automatic welding technology to industrial construction may hold some promise for solving a number of the problems. One possibility might be a machine that automatically aligns the pipe and tackwelds the sections, while providing inspection and protection from the atmosphere.

Bolted connections are generally less of a problem, but time is often lost for rework because the wrong bolts and gaskets have been used. This seems to occur because craftsmen without the correct materials on hand may choose to install incorrect materials rather than make a special trip to get the correct ones. Many construction managers believe this type of problem is likely to continue. The best solution is to improve the design of the connection. Standardized connections, using the same size bolts for most applications, would help as would development of a flange with a built-in gasket.

Pipe Erection: At congested construction sites, lifting pipe into place can be an extremely awkward task. The crowded environment causes a number of problems. Cranes, when they can be used, require room to maneuver, both on the ground and in the air. Communication with the crane sometimes leads to coordination problems. When cranes cannot be used, pipefitters must use manual lifting devices such as chain falls and come-alongs. Lighter and more automatic lifting devices are needed, as are devices that can be set up easily, or devices supported from below rather than from above. In particular, equipment which could rest on the supporting steel of the pipe rack and lift a section of pipe from the ground onto the rack would be useful.

Mechanical and Special-Equipment Installation

A significant portion of industrial and power-plant construction involves installation of mechanical and special equipment. Equipment can generally be classified as rotating or non-rotating. This discussion refers principally to rotating equipment, but to some degree also includes activities in installing non-rotating equipment. The following activities are involved:

1. Equipment procurement
2. Set equipment in place
3. Level equipment within required tolerances
4. Grout in place
5. Align with piping to be connected
6. Clean and flush system prior to start-up

Alignment and leveling were mentioned in every case as the steps which are most complex, skill intensive, and dependent on technical information.

Alignment: Rotating equipment is very sensitive to any pressure placed on it by piping or rotating shafts that are not properly aligned. The tolerances for aligning a rotating shaft to a piece of equipment are therefore extremely small, as little as one three-thousandth of an inch. Achieving such fine tolerances in a construction environment is difficult. The key to success is to develop alignment tools that are entirely internally controlled. Computer chips and lasers allow measurements or increased accuracy. The technology should exist to develop a device that aligns piping and shafts to tolerances programmed into its memory, without the difficulty and time-loss of manual alignment. Another approach to solving alignment problems involves developing materials that do not require such close tolerances. Flexible joints, or self-aligning joints, could greatly ease the installation of rotating equipment. Such joints might also absorb the shock and vibrations generated by the operation of the equipment and thus reduce the stress on that equipment.

Leveling: Allowable tolerances for leveling equipment, while not as close as for alignment, may be as small as one-eighth of an inch between ends. The tools available for leveling, such as hydrosets, are generally adequate in terms of accuracy, but their use is skill-intensive and time-consuming. Laser technology has much potential in the leveling of mechanical and special equipment. Computers also have promise. Finding craftsmen with enough skill required to operate devices that rely on such technology can be a problem, as it has been in such areas as the testing of completed electrical and instrumentation systems.

Electrical Work

Installing electrical work involves these six steps:

1. Procurement
2. Transport materials to erection location
3. Install raceway system (conduit/cable trays)
4. Install wire (pull through conduit/lay in trays)
5. Terminate wire
6. Loop check (test system)

Installing the raceway system and testing the electrical system are the most complex and awkward operations, with pulling and terminating the wire a runner-up. Testing the system, along with pulling the wire, are considered to require the greatest skill. The steps most dependent on technical information are testing the system and terminating the wiring.

Raceways: Most work in raceway installation is performed manually. The operation is extremely time-consuming. Moreover, electrical work generally begins when other crafts such as pipefitters are at their peak on the job. So raceway installation is planned around existing work which, in turn, leads to substantial coordination problems. The tendency of electricians and pipefitters not to share space in the pipe racks requires two racks to be built and compounds coordination problems. An improved raceway design could make sharing the pipe racks more attractive to both crafts. The benefits of technological innovation in raceway design and installation, then, would be realized not only in the operation itself, but also in other crafts.

Testing is the most technologically intensive step in installing an electrical system. It presents a number of special problems, including a need for specially-trained personnel, special equipment, and a long pre-operative phase for the supply of power to the mechanical equipment and the instrumentation. Craftsmen must often communicate with one another during testing while at opposite ends of the site. Possibilities for improvement include the development of testing equipment that could test circuits and terminations without the need for running current through the system. A testing system with a built-in communications device would also be useful, as would multi-purpose equipment that could be programmed to run several different types of checks, including voltage drop, resistance and integrated-circuit tests.

Wire Pulling: Pulling wire through conduit is a sensitive operation which continues to cause problems despite recent improvements.
Damage to the wire is often difficult to avoid in spite of the use of improved wire protection material and lubricants such as soapstone. This operation has been speeded somewhat by the development of mechanical tuggers, but they are unresponsive to the tension on the wire and the operator cannot always tell when the wire snags. A tugger with a built-in drag, similar in concept to a fishing reel, is needed, but even greater improvements can be realized through changes in the nature of wire-pulling itself. Where its use is appropriate, the development of MI (material insulation) cable has eliminated the need for conduit, but such cable has limited applications. Another possibility is the development of a wire puller that can be used as the conduit is installed, perhaps in conjunction with adhesive slip-ring connectors. This would not only reduce the risk of damaging the wire, but would also eliminate the need for an electrical crew to return later to perform the wire-pulling operation.

Terminations are a problem in electrical work partly because of the large number required, and partly because each termination is done manually. Matching up the proper wires can be a problem; it requires both communication and accurate information. Some types of terminations have undergone considerable improvement recently – such as the development of heat-shrink tubing and stress cones for high voltage terminations – but others are greatly in need of attention. Eliminating manual terminations by developing a device that terminates the wire automatically, perhaps by laser fusion, would be a substantial improvement. Plug-in technology is currently in use only in control rooms, where the environment is controlled. Such connections deteriorate rapidly when used in an uncontrolled, open-air environment. Improved materials that resist deterioration would allow the use of this technology in the field, as would development of an air-tight connection similar to prefabricated penetrations designed for nuclear instrumentation. A desirable advance would be combining testing and termination. A plug-in connection that could be tested immediately, or an automatic terminator that tests each connection as it is completed, would greatly simplify testing work.

V

THE POTENTIAL ECONOMIC IMPACT

The responses to both the questionnaire and the interviews imply significant opportunities for cost savings through technological innovations.

Economic assessments of the potential benefits from research are difficult, as for any industry. However, the results from both the questionnaire survey and the job-site interviews indicate that potential economic benefits are very large.

In appraising potential economic benefits, it is useful to focus on the three areas identified as “highest potential” in the questionnaire: piping, mechanical equipment, and electrical.

Each area was identified as having both a high indicator value (representing construction difficulty) and a significant portion of construction costs for all four of the construction sectors studied. If improved technology cut costs in these three areas so that their indicator ratings fell to the average of the other fourteen areas for their types of projects, total project costs would be reduced 2 to 3 percent.

We assumed, for calculation purposes, that the potential cost savings for a given area (such as piping) are proportional to the improvement in its indicator ratings. This assumption is consistent with saying that the indicator ratings are linearly related to labor time.

A second assumption was that the labor component is one-fourth (25%) of the cost of a typical project. Project costs have been further discounted to represent only the construction portions of the projects.

Estimated savings for individual projects (see Table 3) are imposing. For instance, they show that improvement of piping activities alone to the average efficiency of other operations could save more than $5 million per typical project in the power industry alone.

Our method of calculating potential savings has limitations. Other procedures will give different values. Still, it is obvious from our calculations and other results from the survey that very large savings are possible through technological innovations in construction.

TABLE 3
ESTIMATED SAVINGS WITH MODEST IMPROVEMENT IN AREAS OF HIGHEST POTENTIAL*

Construction Category	Average Cost Per Project	Piping	Mechanical Equipment	Electrical	Total Project
			(in millions)		
Buildings	$ 25 million	$ .006	$ .039	$.046	$ .091 million
Light industrial	$120 million	.241	.174	.258	$0.673 million
Heavy industrial	$190 million	3.802	1.002	1.410	$6.214 million
Power plant	$470 million	5.060	3.046	2.744	$10.850 million

Assumptions

1. Labor component is 25% of a project.
2. Improvement would allow piping, mechanical equipment and electrical to achieve ***average*** indicator ratings.

VI

CONCLUSIONS

It is apparent that many needs exist for significant improvements in construction technology. There are many differences between the four sectors of construction that we considered, but many common areas offer opportunities for development. In particular, dramatic economic gains might flow from research and technological improvement in:

Piping

Installation of mechanical equipment

Electrical

Structure

Vessels

Heating, ventilating and air conditioning

Installation of special equipment

Instrumentation

VII

RECOMMENDATIONS

Based on the findings of the study it is recommended that further research and development for the construction industry be focused on the functional activities that have been identified as having the greatest potential for repetitive payback.

VIII

REFERENCES

Available upon request from:

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The Department of Civil Engineering, ECJ 5.2, The University of Texas at Austin, Austin, Texas 78712.

Construction Areas with Significant Technological Research Opportunities, a report by Stephen M. Sheppard and Richard L. Tucker, 15 February 1982.

***Construction Activities with Significant Technological Research Opportunities**, a* report by John A. Rickard and Richard L. Tucker, 1 March 1 982

CICE REPORTS

The Findings and Recommendations of The Business Roundtable's Construction Industry Cost Effectiveness project are included in the Reports listed below. Copies may be obtained at no cost by writing to The Business Roundtable.

Project Management -- Study Area A

- A-1 Measuring Productivity in Construction
- A-2 Construction Labor Motivation
- A-3 Improving Construction Safety Performance
- A-4 First and Second Level Supervisory Training
- A-5 Management Education and Academic Relations
- A-6 Modern Management Systems
- A-7 Contractual Arrangements

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- B-2 Technological Progress in the Construction Industry
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- C-3 Contractor Supervision in Unionized Construction
- C-4 Constraints Imposed by Collective Bargaining Agreements
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- Excellence Will Make A Difference (A-3)