Methods to Identify and Assess New Building Technology

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Abstract: The lack of a coordinated industry-wide effort to provide the emerging construction technological information is one of the reasons behind the slow adoption of new technologies in the U.S. construction industry. This paper reports the results of a research project on this critical issue. The purpose of the research was to develop a formalized mechanism to identify new building technologies available for use by the construction industry and to assess the potential impact of the identified new technologies on the U.S. Army Corps of Engineers construction program. There are many means to identify new building technologies. Information can be obtained through periodical search, code organizations, testing laboratories, the U.S. Patent and Trademark Department, advertising in trade magazines, and interviewing experts. The impact of each identified technology on the corps' construction programs was assessed in terms of the corps' five-year plans, the Means and Dodge manuals, and building systems affected by the technology. Other assessed features were a cost benefit comparison and the risk associated to implement the technology. The findings of this research are encouraging. A generic framework has been developed, and the areas that need to be further improved have been pointed out.

Introduction

The U.S. construction industry has been long criticized for its slow adoption of new technology (Kelly 1986). The failure to apply new technology is believed to be one of the primary causes of poor productivity, schedule delay, and cost overrun on many projects in recent years (Tucker 1986).

According to the Business Roundtable Construction-Industry Cost Effectiveness (CICE) report (Business Roundtable 1982), one of the four principal impediments to implementing new technologies is the lack of information for those who may apply these technologies. There is no coordinated effort to gather, manage, and provide this information industry-wide. Without being knowledgeable or even aware of a new technology, a potential user cannot recognize its advantages or make the most efficient applications. Moreover, potential users may become fearful of risks and legal liabilities involved with possible failure. In order to address this issue in the military construction environment, and still be able to take

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advantage of new technologies as they emerge on the marketplace, research was conducted by the U.S. Army Construction Engineering Research Laboratory (USA-CERL) and Purdue University. The purpose of the research was to develop a formalized mechanism to identify new building technologies on the U.S. Army Corps of Engineers construction program. USA-CERL would then conduct more detailed evaluations of those new technologies that exhibit potentially greater advantages.

The objectives of this paper are:

1. To report the research findings of the development of a mechanism to seek new technologies.
2. To introduce the system used for the assessment of impact on the U.S. Army construction program.
3. To recommend future research.

This paper will begin with the introduction of some background on the current corps practice of introducing new building technology into its construction program. Following this introduction, the methodology of how to identify new building technologies will be illustrated. The system to assess the impact of identified new building technologies on the U.S. Army construction program will be presented. Meanwhile, the framework to screen the identified technologies for further evaluation will be explained. Finally, the writers will present the conclusions of the research and point out the direction of future research. In order to define a more manageable task, research focused on building technologies. This research used building research as a base to build up a generic framework applicable to a broader range of construction technologies.

The method for identifying new technologies was a largely subjective process. Building systems, subsystems, or products were evaluated on the "newness" of the technology—how recently it emerged on the marketplace, general recognition by others as an innovative technology, general acceptance within the construction industry, frequency of appearances in articles and advertisements, and code-group listings. For the convenience of discussion, the terms "new technology" and "innovative technology" are used interchangeably in this paper.

Background

At present, the U.S. Army Corps of Engineers has no single formal mechanism to identify, evaluate, and introduce new building technologies (products and construction systems) into the corps' construction environment.

Frequently, the introduction of new technologies occurs on an ad hoc basis. When this happens, new technologies are brought to the corps' attention by any of the various means and the corps' evaluation and implementation must occur relatively quickly. This process yields varying degrees of success. More often, introduction of new building technologies is an evolutionary process where acceptability is based on positive experiences in other markets. More effective methods than either one of these can be developed.

Therefore, a systematic methodology is needed. When the technologies have been evaluated and accepted according to certain standard proce-

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dures, the Corps of Engineers will be able to use new technologies with more confidence. Moreover, actively seeking new building technologies will place the corps in a proactive mode, rather than a reactive mode.

Methodology and Results for Identification

The development of a formalized mechanism to identify new building technologies was initiated by conducting an extensive library search. "Pilot" telephone interviews were conducted with individuals who would be knowledgeable about new technologies and their sources. Fourteen construction industry magazines and journals with sections on new products and emerging technologies were identified and the editors were interviewed. Twenty-five officials from professional associations, testing laboratories, building-code organizations, building-product manufacturing associations, and the U. S. Department of Commerce were also contacted.

The interviews involved specific questions and discussions focused on what information was available from each individual or source, and how this information was available from each individual or source, and how this information should be obtained. To find the desired data, the editors were asked to send copies of appropriate information and any further suggestions.

Each telephone interview was documented immediately by the interviewer. A subjective opinion of each organization's ability to contribute to the study was a part of the documentation. Each organization's willingness and capacity to contribute were also noted.

From these interviews and the literature search, a plan was developed to perform the "full-scale" stage of the study. First, a periodical search was undertaken to try to identify new technologies. Trade magazines and journals from the past five years were scrutinized. Once a new technology was found, its description and use were written from the given material. The source of information and the source of supply was also taken down for reference and possible future use.

This is a long and tedious identification task, and the information provided is usually not sufficient to fully complete evaluation. However, many innovative building technologies were found during this phase. This method proved to be an adequate source for identification, but lacked sufficient information for future evaluation.

Second, five code organizations were contacted. They were the Association of Major City Building Officials, the Council of American Building Officials, the National Conference of States on Building Codes and Standards, the Building Officials and Code Administrators, and the International Conference of Building Officials.

Each code organization is observed essentially on a regional basis. Manufacturers of construction-related products submit news releases and any other necessary product information to the model code organization to conduct an evaluation. The code organization then publishes a report indicating whether the product is in compliance with the code and approved under that code. Approval under the governing code is essential for the marketability of a product within a particular region.

A code report typically consists of a description, application, identification, and important properties of the subject product, as well as the findings of the evaluation. This information is useful when scanning the industry for new building technologies. These reports can be obtained from the code organizations on a subscription basis and can provide a concise and timely source of information on building products that are emerging on the construction marketplace.

Third, the U.S. Patent and Trademark Office's Division of Building Structures and Components can also be utilized to collect innovative technology information. Building construction products could be found under static structures (e.g., buildings—class 52 ([U.S. Patent and Trademark Office 1981]). The patent office has 69 patent depository libraries throughout the United States where a computer database called Lexis can be found. Within Lexis is Lexpat, which is a full context of every U.S. patent given. Under class 52 over 65,000 patents have been issued since 1975. On-line searches can be conducted to identify specific technologies. The company's name and address, along with a copy of the patent itself, are also available. In order to see what was contained in a patent and test how long it took to receive a copy, three different patents related to building systems were ordered. Each copy of a patent costs $1.50.

These reports were received approximately two weeks after their request was submitted. The patent document follows a prescribed format. General information is supplied on the first page and includes the product name, patent number, date of issue, inventors, and all references cited in the patent document. A brief abstract is also included. All detailed drawings of the invention follow the first page.

Background information, rationale for the invention, and the principal objective follow in the background and summary sections of the report. Detailed descriptions of drawings, parts, assembly, and uses follow under "Descriptions of the Preferred Embodiments." Finally, the inventory list of claims for the product is provided.

The patent document provides a great deal of information on the invention itself, but does not have any information about the inventions' availability, cost, or comparison to existing technology. Furthermore, as only patentable items are documented, other forms of nonpatentable innovative building technologies are not addressed through this resource.

Fourth, many unknown manufacturers or building technology developers are scattered over the nation. One way to initiate a relationship with them is to put an advertisement in various popular building/construction magazines. Through this means, interested parties could participate in the study without being identified through previous channels. A representative publication was chosen and an advertisement was placed in it. The feasibility of an advertising mechanism was evaluated from the responses received. The advertisement placed in the March 1987 issue of *Building Design & Construction* did not receive much attention; 16 responses were received on new technologies. If it had been placed in more publications, the results may have been different. Another reason for low response may have been the advertisement itself. Perhaps, if it had been more detailed, there would have been more interest in the study. The collection of information through such an advertisement is suspect and is not believed to be as effective as other methods.

Fifth, three testing organizations were contacted: the American Society for Nondestructive Testing (ASNT); the American Society for Testing and

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Materials (ASTM); and the American Society of Test Engineers (ASTE). These organizations usually publish documents with feature articles on new materials, products, and technology.

Sixth, when writing articles about new and innovative technology, magazine editors frequently consult with experts in the appropriate field. The editors usually have a bank of names, addresses, and telephone numbers of experts in each field of concentration within the construction industry. They use these experts as supplements to articles by getting facts, opinions, and foresight as to where there particular specialty is headed. A list of experts was obtained from the Council of Tall Buildings and Urban Habitat and from several universities.

Once the interviewers got in touch with the experts, they generally could point out the new technologies in their specialized areas and elaborate advantages, disadvantages, and future trends. Finding individuals and generating expert banks in each area of building technology could be of great help in identifying and evaluating new building technologies.

Data Acquisition

Although many new building technologies and products were found through the aforementioned mechanisms, the information collected was usually not sufficient to fully evaluate the technologies and products. To obtain specific information and to facilitate the evaluation process with a computer clearinghouse, Purdue researchers initiated a data acquisition of potential sources of new building technologies. The acquired data consisted of the following contents:

1. Product name.
2. A list of components of the construction process that the technology would affect. The questionnaire asked under which of the following nine categories did the proposed building construction technology fall: foundations, substructure, superstructure, exterior closure, roofing, interior construction, mechanical, electrical, and specialities. Each of these are further broken down into subcategories. By determining this, it's easier to code each new technology into the computer program by these categories.
3. A brief description of the new building system. What are the general characteristics of the technology?
4. Amount of testing. Has the new technology been through any type of testing and by whom? This will show what type of reliability the product has.
5. Codes. Does the new technology comply with any codes? A list of eight codes and the organizations that enforce them was given in a checklist. If the technology was in compliance with codes not given, space was provided to write them. This was important because there was a possibility that a new technology must be in compliance with certain codes in order to implement it.
6. U.S. patent. Does the new product have a U.S. patent?
7. Availability in the market. If there are any restrictions to where the new product is currently available, it will be noted here.
8. Design and construction process changes. Are any alterations of the design and construction process required to implement the technology?

The reason for this question is to determine the overall impact of implementing the new technology. If the new technology is to be used, will other construction technologies or processes have to be altered to accommodate it? If so, what are the impacts?

9. List of the major benefits and shortcomings of the product.

10. Changes in systems. What system, if any, will the new technology replace? What systems will not be used because of the new product?

11. Comparison of existing system with the new one. Is the productivity of the implementation of the new system higher, lower, or the same as the already existing system? Quality: Is the finished product of higher, lower, or of the same quality? Safety: Compare the safety of implementation and of the finished product. Cost: What is the cost of the new technology in U.S. dollars per unit and is the new technology more expensive, cheaper, or the same as the existing technology?

12. Prospects for the new technology. What does the future hold for the new technology? What, in the foreseeable future, will be the innovations in the area of this technology? This question will help in predicting future trends in the construction industry.

13. Brochures and promotional information on new technology. This material can provide information not obtained through the questionnaire and will provide graphic and pictorial material to supplement the technology's descriptions.

During the acquisition of the data, a list of over 3,000 advertisers was obtained from a publisher. This list contained company names, addresses, and a point of contact. It was anticipated that contacting these companies could provide insight regarding future technology developments. From that list, a sample of 306 firms was selected and contacted by researchers. Of these, 69 firms completed and returned the data sheet. A completed sample data sheet is shown in Appendix I.

Impact Assessment

After innovative technologies had been identified and compiled, evaluation commenced. The first phase was to examine their impact on the building program of military construction for the Army (MCA).

The impact-assessment phase of the forecast and evaluation exercise is used to prioritize identified innovative technologies. As it is not feasible to conduct a detailed evaluation on all identified innovative technologies, those with technologies receiving the highest priority ranking are those that have the greatest potential to provide a cost or performance benefit to the MC program. Since the Army has limited resources to evaluate all the identified innovative technologies, those with the greatest impact potential will be evaluated first.

The impact assessment can also be used as a means to "screen out" technologies that will not be advantageous to the Corps. Some building technologies with commercial market applications may not have had comparable applications within the military building environment. Furthermore, shortcomings in a technology will be made apparent through a preliminary screening. These may include inadequacies in performance, higher cost that cannot be justified by performance, or insufficient devel-

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opment that would present an unacceptable risk if the technology were implemented in its existing form.

This phase consists of two stages. In the first stage, an "impact factor" will be generated based on the cost and volume of construction represented in the MCA program. In the second stage, scalar factors for cost benefit and risk will be generated and incorporated in the impact assessment. Based on the combined results of the two stages, a prioritized list of technologies will be developed to help determine which technologies should be evaluated in greater detail before others.

It should be noted that the purpose of this impact assessment, at least for USA-CERL's purposes, is to help prioritize the commitment of resources for more detailed evaluations. It is not intended to "qualify" or "disqualify" technologies for further consideration, nor is it intended to be the sole, inflexible determinate in conducting further evaluations. Other factors can be acknowledged, as appropriate for individual situations.

MCA Impact Factor

The MCA impact factor is a relative numerical representation of a particular technology's potential impact on the MCA program. It is derived by first identifying the cumulative volume of construction of each Army facility type in the five-year MCA program, and then determining the extent to which the technology can be applied within the MCA program. A technology that may affect a relatively larger portion of the MCA program will have a relatively higher MCA impact factor.

TABLE 1. Cost Percentages of Building Types

	Year						
Building Types (1)	1987 (2)	1988 (3)	1989 (4)	1999 (5)	1991 (6)	Total (7)	Percentage total (8)
Communications	18,200	20,487	9,842	11,636	0	60,165	0.938
Operational	60,830	52,433	135,730	61,863	38,342	349,198	5.442
Training	162,350	80,215	117,619	56,237	44,666	461,087	7.185
Maintenance	353,328	503,547	440,960	176,434	243,793	1,718,060	26.776
Production	0	0	0	0	9,045	9,045	0.141
Laboratories	47,780	31,273	105,028	110,882	51,182	347,143	5.410
Ammunition storage	6,700	48,547	27,575	0	23,662	106,484	1.660
Cold storage	0	7,914	0	6,502	1,663	16,078	0.251
General storage	16,170	115,373	56,398	33,763	49,102	270,806	4.221
Hospital	0	53,400	2,500	51,900	0	107,800	1.680
Dental clinics	4,550	0	0	3,400	0	7,950	0.124
Medical clinics	18,450	10,452	6,363	0	9,787	45,050	0.703
Administrative	44,990	135,683	148,012	80,075	56,124	465,004	7.247
Family housing	0	0	0	0	0	0	0.000
Unaccompanied enlisted quarters	266,041	275,071	257,798	313,500	175,755	1,310,163	20.419
Dining	37,050	19,699	29,532	33,270	28,627	148,348	2.312
Detached facility	0	22,332	17,699	42,835	18,333	101,192	1.577
Unaccompanied officer quarters	32,640	38,254	35,025	84,765	22,597	216,485	3.374
Support and service	9,690	10,124	7,025	4,212	45,703	80,754	1.255
Welfare and recreation	88,900	116,035	63,352	56,762	250,523	595,595	9.282
Total MCA building Cont.	1,189,851	1,541,140	1,484,450	1,128,057	1,072,889	6,416,407	100.000

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TABLE 2. Cost Percentages of Building Systems

Building Type (1)	Foundation (2)	Substructure (3)	Superstructure (4)	Exterior (5)	Roofs (6)	Interior (7)	Mechanical (8)	Electrical (9)	Specialty (10)	Sum (11)
Communications	1.7	1.5	45.0	6.2	2.5	7.3	13.6	11.6	10.7	100.1
Operational	8.4	10.4	10.4	25.4	7.6	1.4	20.8	15.6	0.0	100.0
Training	4.1	5.9	12.5	17.0	4.2	23.7	17.8	13.4	1.4	100.0
Maintenance	11.6	7.4	7.0	15.1	10.7	8.0	21.6	9.0	9.5	99.9
Production	8.3	7.7	11.7	11.5	10.1	10.2	25.5	14.9	0.0	99.9
Laboratories	10.0	4.4	7.8	8.5	5.5	25.7	26.2	9.9	2.0	100.0
Ammunition storage	4.8	5.1	27.7	10.6	3.7	16.8	14.7	9.3	7.8	100.5
Cold storage	3.4	6.7	21.9	10.2	10.6	12.2	16.9	9.8	8.2	99.8
General storage	9.1	16.8	12.9	13.3	10.5	7.5	17.7	8.2	4.1	100.1
Hospital	1.2	0.7	13.9	10.5	0.9	33.7	14.5	11.9	12.8	99.9
Dental clinics	0.0	5.1	6.1	14.2	32.9	26.7	8.4	2.4	2.3	98.1
Medical clinics	6.7	2.8	15.6	1.2	0.7	21.1	23.4	13.4	15.1	100.0
Administrative	2.9	2.0	14.1	11.3	2.4	25.1	23.2	14.1	5.0	100.1
Family housing	11.8	0.0	18.8	10.5	3.4	31.5	14.5	3.2	6.5	100.2
Unaccompanied enlisted quarters	2.7	1.6	18.4	13.3	2.1	24.5	19.2	10.3	7.6	99.6
Dining	6.3	3.8	24.2	14.7	5.5	15.1	6.6	2.6	21.0	99.8
Detached facility	10.7	5.4	7.2	18.2	8.0	11.2	16.4	22.9	0.0	100.0
Unaccompanied officer quarters	4.1	2.2	13.2	17.9	2.7	29.8	14.6	7.9	7.6	100.0
Support and service	7.5	5.6	6.5	17.6	7.7	26.9	15.4	12.8	0.0	100.0
Welfare and recreation	11.8	4.9	7.2	16.5	7.7	25.2	18.3	5.4	3.0	100.0
Average system (%)	6.4	5.8	15.1	13.2	7.0	15.2	17.5	10.5	6.2	100.0

The initial step was to determine the relative contribution of each facility type to the total MCA program. Table 1 summarizes Army facility types by general category, as described in *Army Regulation 415-28* (U.S. Army 1981). A general categorization will serve the purposes of the impact assessments. The programmed amounts (in dollars) for each facility type is displayed for each of the next five years. Totals are calculated for each facility type and for the five-year MCA program. The last column in the table represents the relative contribution of each facility to the total MCA program as a percentage of the total. For example, unaccompanied enlisted quarters represent over 20% of the total MCA program (by cost) for the next five years. If unaccompanied officers quarters, a similar type of facility, is added, almost 24% of the total MCA program involves a "housing" type of facility. The trend indicated here is that almost one quarter of the MCA program (by cost) involves "housing."

A building technology will most likely affect only a portion of a building—a system or component—rather than an entire building. Each MCA facility type can be divided into its major systems. The portion of the total building attributable to each building system can be represented as a percentage of the total building cost. Table 2 displays these percentages. This data was derived using commonly available construction industry cost guides (McGraw-Hill Information Systems Co. 1985; Robert Snow Means Co., Inc. 1985, 1986). The sources for the building systems cost percentages is given in Table 3.

The *Dodge Construction Systems Cost Guide* displays summary cost according to building types. For a given building type, square-foot costs

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TABLE 3. Correlation between Building Type and Type of Cost Guide

Building Type (1)	Cost-guide building type (2)	Cost guide[a] (3)	Page number in guide (4)
Communications	Telecommunications center	Dodge	58
Operational	Hanger—aircraft	Means	234
Training	School—vocational	Means	188
Maintenance	Garage—repair	Means	126
Production	Factory—one story	Means	110
Laboratories	College—laboratory	Means	100
Ammunition storage	National—guard armory	Dodge	47
Cold storage	Refrigerated warehouses	Dodge	71
General storage	Warehouse	Means	208
Hospital	Warehouse	Means	208
Dental clinics	Hospital, four to eight stories	Means	138
Dental clinics	Dental laboratory	Dodge	37
Medical clinics	Medical center	Dodge	45
Administrative	Office, two to four stories	Means	162
Family housing	Average townhouse, eight units	Means Res.	249
Unaccompanied enlisted quarters	College dormitory, two to three stories	Means	96
Dining	Camp dining hall	Dodge	32
Detached facility	Laundromat	Means	146
Unaccompanied officer quarters	Apartments, one to three stories	Means	172
Support and service	Town hall, one story	Means	204
Welfare and recreation	Community center	Means	104

[a]Dodge refers to *Dodge Construction Systems Costs* (McGraw-Hill Information Systems Co. 1986); Means refers to *Means Square Foot Costs* (Robert Snow Means Co. Inc., 1985); and Means Res. refers to *Means Residential/Light Commercial Cost Data* (Robert Snow Means Co., Inc. 1986).

and percentages for each building system and a total building cost are displayed. High, average, and low costs for the facility type are provided. For this study, the "average" building system percentages were taken directly from this guide.

The *Means Square Foot Cost Manual* also provides cost data according to building type. Cost figures are provided for the various components and materials comprising a system; a total cost figure (per square foot) for the system is then given. However, no cost percentage relative to the total building cost is displayed. This percentage was derived by adding the systems' costs to obtain a total building cost, then calculating the percentage represented by each system.

For example, the college dormitory described in the *Means Square Foot Cost Manual* is similar to the unaccompanied enlisted quarters shown in Table 2. Using that source, the average cost per squae foot for the exterior enclosure is $6.45. The total average cost for that building type is $48.43. Therefore, the percentage value is 13.3%, as shown in Table 2 (Column 5, Row 15). The sum of the building systems' percentages for each building type should always equal 100.

The cost guides used were 1985 and 1986 editions. It must be emphasized that the critical figures are the percentages: the portions of the systems relative to the total building. The absolute dollar figures will

TABLE 4. Example Calculation for Impact Factor (Technology Is Glass-Fiber Reinforced Concrete Closure System; and System Is Exterior Closure)

Building types that could be affected by the technology (1)	Percentage of MCA building program affected by the building (2)	Percentage of building cost affected by the system (3)	Percentage of system affected by technology	
			Low (4)	High (5)
Communications	0.94	6.20	70.00	85.00
Operational	5.44	25.40	70.00	90.00
Training	7.19	17.00	65.00	85.00
Maintenance	26.78	15.10	85.00	100.00
Production	0.14	11.50	85.00	100.00
Laboratories	5.41	8.50	65.00	90.00
Ammunition storage	1.66	10.60	90.00	100.00
Cold storage	0.25	10.20	95.00	100.00
General storage	4.22	13.30	90.00	100.00
Hospital	1.68	10.50	55.00	85.00
Dental clinics	0.12	14.20	55.00	85.00
Medical clinics	0.70	1.20	55.00	85.00
Administrative	7.25	11.30	60.00	90.00
Family housing	0.00	10.50	55.00	80.00
Unaccompanied enlisted quarters	20.42	13.30	60.00	80.00
Dining	2.31	14.70	60.00	85.00
Detached facility	1.58	18.20	75.00	90.00
Unaccompanied officer quarters	3.37	17.90	60.00	80.00
Support and service	1.26	17.60	80.00	95.00
Welfare and recreation	9.28	16.50	80.00	95.00

Note: Total system impact factor range is 10.70 ~ 13.41%.

become outdated quickly, but the relative percentages should be stable over a few years' time. The building systems' cost percentage values, however, should be recalculated periodically.

The next step is to determine the extent to which a particular technology can reasonably be used in a building system. A building product, as developed and marketed, will comprise a part of a building system but generally not the entire system. For example, a prefabricated wall system may include all opaque panels, fasteners, gaskets, battens, coping, flashing, etc. Window units, entrances, and accent materials, however, may have to be obtained through other sources. These values were determined by the researchers' experience and judgment to reflect the extent to which a technology could reasonably be applied to the affected building system. A high and low value for each technology are defined. The building type also influences the percentage of the system that could be impacted by the subject technology.

The MCA impact tables display the potential impact a building technology may have on the MCA program. One table is developed for each building system to which the subject technology can apply. An example is given in Table 4, describing the potential impact of a glass-fiber reinforced concrete wall panel system on the exterior wall systems of the MCA facility types. The facility types are shown in Column 1. Column 2 shows the relative percentages of each facility type within the total MCA program. These figures are taken from the last column in Table 1 and are the same for all MCA impact tables. Column 3 of Table 4 shows the relative percentage of the subject building system to each facility type. These figures are taken from Table 2 and will vary according to the building systems. The fourth and fifth columns represent a range within which a technology could affect the subject system for each facility type. The last row of Table 4 is the range of the potential impact the technology may have on the total MCA building program for the subject building system. The algebraic expression for this relationship is:

Total system impact factor range

= Sum of [(Percent of MCA building program)

× (Percent of building cost affected by the system)

× (Percent of system affected by technology)] . . . . (1)

This calculation is performed for every facility type, both for the low and high ends of the range. Next, the factors generated for each end of the ranges for each facility type are summed to determine the high and low ends of the total systems impact factor. This process is repeated for each building system to which the identified technology can apply.

Finally, a total MCA impact-factor range is calculated for each building technology. This factor is the sum of the total system impact factors for each affected building system. Based on the total MCA impact-factor range, the technologies identified through the forecasting exercise can be ranked from most to least potential impact. As the potential for greater benefits is implied by a higher potential impact, this ranking can be used to help prioritize further detailed evaluation efforts.

Other Impact-Assessment Factors

In addition to the MCA impact factor, several other scalar factors are used to complete the impact assessment for innovative building technologies. Whereas the impact factor is concerned with determining the potential dollar impact on the Army construction program, the other assessment factors deal with the cost benefits and the risk involved in using the new technology. They will be used to further the filtering process that determines which technologies have the highest evaluation priority.

The additional assessment factors are not intended to provide a ranking to the technology being screened. They will be used as further qualifiers for decisions regarding which technologies have the highest evaluation priorities. For instance, after the assessment factors are applied to a particular technology, it may become evident that the product has certain features associated with it that may provide more than just an economical benefit to the corps. These may be reduced operations and maintenance cost or a benefit in quality over existing products that will be replaced by the new technologies.

Another benefit of using the additional assessment factors is a determination of the risk involved if the new technology is implemented by the

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Corps of Engineers. The risk determination will be used to assess the technology's level of innovation and current level of use.

Cost-Benefit Rating

The MCA impact factor indicates the potential effect a new technology will have on the MCA program (in terms of dollars of construction affected), whereas the cost-benefit rating provides an indication of the actual cost benefits (if they exist) of implementing the new technology. A new building technology could affect a large portion of the MCA construction program; however, the effect could be positive or negative. The implementation of new systems could cost more than the existing products without an equivalent upgrade in performance. On the other hand, the new product might save money and provide a better quality product. This is what the cost-benefit rating is intended to indicate, the actual cost of the product (both initial cost and operation and maintenance cost) as compared to the product(s) it will replace, and the performance benefit or lack thereof that will be realized.

The cost-benefit rating is a qualitative factor based on cost information at hand. It is not intended to imply a precise cost estimate or require an extensive economic analysis. In order to determine the cost-benefit factor, the rater will have to rely on manufacturer data regarding price information. Based on the manufacturer cost data, a point of comparison between the new product and the product(s) it will replace will have to be drawn. This will require cost data on existing in-place technologies. Several sources of information can be used to obtain this data, including Army cost estimates, contractor data, cost-estimating guides, and product literature. If all the applicable cost data are found, comparisons can be drawn between the new technology and the technology it will replace on both initial cost and operations and maintenance cost.

The other portion of this factor is the benefit rating. The new product may provide a performance benefit over building technologies now being used by the corps. This may be because of a better quality product, or because of the capabilities the new technology may possess. On the other hand, the new technology may exhibit no improvement in actual performance, or it could provide the same qualities existing technologies offer. The benefit determination is a qualitative judgment based on construction technology experience.

Cost-Benefit Rating Process

In order to complete the cost-benefit rating process, evaluators will need to have cost information on both the existing and innovative technology, obtained from the sources as listed. They will also need to have basic performance information, which can be taken from product literature from the manufacturer or from individuals who have used the identified technology. Based on this data, they will make the following determinations:

1. Initial cost:
   a. The product has a lower initial cost than existing technologies being used by the corps.
   b. The product has a relatively comparable initial cost as compared to existing technologies.

c. The product has a higher initial cost than existing technologies.
d. There is insufficient data to determine the initial cost.

2. Operation and maintenance cost (O/M):
a. The technology has a lower O/M cost than existing technologies being used by the corps.
b. the technology has a relatively comparable O/M cost as compared to existing technologies.
c. The technology has a higher O/M cost than existing technologies.
d. Insufficient data exists to make an O/M cost comparison.
3. Performance benefits:
a. The performance of the identified technology is of lower quality than existing technologies.
b. The performance of the innovative technology is relatively comparable to existing technologies.
c. The performance of the identified technology is of higher quality than existing technologies.
d. Insufficient data exists to determine the performance benefits of the innovative technology.

One statement from each of the three categories will be applied to each identified innovative technology. Any notes or explanations considered important can be included with the rating statements. Insufficient data statements will not be considered as a negative in cases where insufficient data exists to complete the rating process; however, technologies with all cost and performance information available will most likely have higher priority for evaluation selection. Concerted efforts should be made to obtain all the necessary product information for each identified technology.

Risk Assessment

There is a certain risk involved in the utilization of innovative technologies, due to the relative "newness" of the product and its level of implementation and incorporation into standard construction practices. It should be noted that the higher the risk involved in implementing the technology, the greater the payoff could be. However, the outcome of failure of a high-risk technology could be devastating to the individuals involved in its implementation. Therefore, a measure of the risk involved with the implementation of each innovative technology must be made. Technologies in the highest risk categories may need further development and acceptance into standard practice before the Corps chooses to implement them. Medium-risk technologies may require further evaluation by the Corps before they will be used, and the lower-risk technologies could be ready for implementation.

The risk assessment is designed to recognize the differences in the various levels of innovation and to place the appropriate emphasis on the technology based on the identified "risk classification." A technology that has been accepted into wide use will inherently have less risk associated with it than would a technology that is still "on the drawing board."

A sequential screen was developed to provide a risk classification for each identified technology. Once again, basic product and/or technology information obtained through product literature or from a manufacturer representative will be needed to complete the risk level of commercializa-

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tion, practice, or industry acceptance. A series of ten questions was developed in order to provide the risk classification (Cornelio et al. 1987).

- Level 9: Is the innovation based on sound design principles?
- Level 8: Have test models of the innovation been constructed?
- Level 7: Has a full-scale version of the innovation been constructed?
- Level 6: Has there been a commercial installation of the innovation?
- Level 5: Have there been more than ten commercial installations of the innovation?
- Level 4: Has the innovation been accepted into a building code?
- Level 3: Has the innovation been accepted into any building code?
- Level 2: Has the innovation been used in environmental conditions similar to those for the proposed design site?
- Level 1: Are there multiple suppliers of the innovation?
- Level 0: Has the innovation been used successfully in any Corps of Engineers construction projects?

The personnel involved in the screening process will provide a risk classification based on this sequence of questions, level 9 being the highest risk and level 0 being the lowest. However, no determination as to the "fate" of the technology will be made at this point.

Following the complete impact assessment process, three factors will be available in order to determine the evaluation priorities. These will be the MCA impact factor, a cost-benefit rating, and a risk determination. The assessment will not provide a single numeric value used to judge the technologies' impact potential. However, the data provided will enable an individual with construction expertise to make a proper decision on which technologies to evaluate. For instance, a technology that has a high MCA impact-factor score may pose too great a risk for the corps to implement; therefore a technology with a lower MCA impact-factor score and with virtually no risk of implementation may be selected for evaluation over the higher-impact technology. Furthermore, based on the expertise and experience of the system evaluator, technologies could be selected for further testing and implementation.

Conclusions and Recommendations

New technologies are emerging in every phase of the construction process. However, the industry as a whole, both private and public, is very slow in adopting. To keep the U.S. construction industry competitive with international competition, a systematic search, assessment, and introduction of new technologies into the construction industry is necessary. Thus, the new technologies can be applied cost effectively while maintaining quality and structural integrity.

There are many means to identify new building technologies. Information can be obtained through periodical search, code organizations, testing laboratories, and the U.S. Patent and Trademark Department, putting advertisements in trade magazines, and interviewing experts. Of these means evaluated in this study, it appears that direct acquisition of data from the manufacturers is the most effective. It received a very good response and collected the specific information needed.

The impact of each identified technology on MCA programs was assessed in terms of MCA plans for the next five years, the Means and

Dodge manuals, and building systems affected by the technology. Other assessed features were a cost-benefit rating and the risk associated with implementing the technology.

Although a definitive conclusion may not be made at this stage, the findings of this research are encouraging. A generic framework has been developed, and the areas that need to be further refined have been allocated as follows:

1. A questionnaire survey for data acquisition could be installed on a regular basis in the future (annually or semiannually). This would be similar to the surveys periodically performed by the Bureau of Labor Statistics in the investigation of construction employment or by *Engineering News Record* in the compilation of the top 400 contractors. Thus, the collected data could be updated. Also, any new technology just coming into the market could be identified.
2. Objective methods of quantifying impact by the identified new technologies should be embodied into the assessment of cost-benefit rating and risk involved.
3. An integrated computerized clearinghouse must be further examined. It is foreseeable that huge amounts of data need to be processed. Common database interfacing with many internal assessment programs and external applications through rule-based reasoning to suggest appropriate actions need to be included in the future study.

Appendix I. Sample Data Sheet

Does your company currently produce a new technologically advanced building system/product? Yes _____ No_____

If so, please list the name(s) of these systems

For each new building system/product listed, please check which components of the construction process this technology will affect. (Please make separate copies of this questionnaire for each of your new products.)

- Foundations _____
  - Footings _____
  - Piles _____
  - Wall _____
  - Other (please specify) _____
- Substructure _____
  - Slab on grade _____
  - Other (please specify) _____
- Superstructure _____
  - Columns and beams _____
  - Roofs _____
  - Stairs _____
  - Floors _____

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- Exterior closure ______
  - Finishes ______
  - Doors ______
  - Windows ______
  - Walls __x__
  - Insulation __x__
- Interior Construction ______
  - Doors ______
  - Partitions ______
  - Ceiling finishes ______
  - Wall finishes ______
- Electrical
  - Service ______
  - Special ______
  - Lighting and power ______
- Roofing ______
  - Special ______
  - Coverings ______
  - Flashing ______
  - Insulation ______
- Mechanical ______
  - Plumbing ______
  - Fire Protection ______
  - Heating ______
  - Air conditioning ______
- Specialties ______
  - Conveying ______
  - Fixed equipment ______
  - Elevators ______
  - Other (Please specify) ______

Give a brief description of each new building system/product: an exterior siding material with a 0.5-in.- (1.27-cm-) thick brick facing mounted on a Dow styrofoam 1-in.- (2.54-cm-) (or 2-in.- [5.08-cm-]) thick backer board—see attached literature for more complete description.
Has this new building system/product been through any kind of testing? Yes __x__ No _____
Which organization tested the new system/product? Testing Engineers & Consultants, Inc., Troy, Michigan; ______ Southwest Research Institute, San Antonio, Texas ______
Is this system in compliance with any codes? Yes __x__ No _____
Please check codes with which this system is in compliance.

1. Basic Building Code (BOCA) 80-77
2. Uniform Building Code (ICBO) _____
3. Southern Standard Building Code (SBCCI) 8289
4. National Building Code (AIA) _____
5. National Electric Code (AIA) _____
6. National Plumbing Code (APHA) _____
7. Life Safety Code (NFPA) _____
8. American Standard Safety Code for Elevators, Dumbwaiters, and Escalators (ASME) _____

If the new building system/product complies with a code not listed please specify the name of the code and the coding organization: FHA HUD 1076A
Does this system/product have a U.S. patent? Yes __x__ No _____

Testing reports available:

ASTM-E330-79 internal/external wind pressure
ASTM Model E108 full-scale fire test
ASTM C666 method B—freeze/thaw weathering
impact resistance—weighted dart drop

Is this system/product currently available in the construction market? Yes __X__ No _____

Does the system/product require that other areas of the design and construction process be changed? Yes __X__ No _____

If yes, what has to be changed? Eliminate brick ledge plus minor wood trim changes.

List the five major benefits and shortcomings of the new building system/product.

Benefits	Shortcomings
1. Real brick appearance	1. Less impact resistance than 4–in. (10.lb–cm–) thick masonry
2. High insulation value	2. Some limitation in design of brick pattern
3. Does not require foundation	3. Limited brick color selections
4. Attaches to any structural sound wall	4. ________________
5. Less costly than 4-in. (10.lb-cm-)	5. ________________

Is your building system/product
_____ Improved version of an existing model
__X__ Completely new

What systems, if any, will this new building system/product replace? 4-in.-thick masonry veneer

How does the building system/product compare with already existing systems?

• Productivity of implementation	Higher _X_	Same ___	Lower ___
• Quality	Higher ___	Same _X_	Lower ___
• Cost	Higher ___	Same ___	Lower _X_
• Safety of implementation	Higher _X_	Same ___	Lower ___
• Safety of finished product	Higher _X_	Same ___	Lower ___

Any other comments on preceding question. The R-Brick Panel System™ is not a masonry product, it is a brick siding and exterior finish material. What is the unit cost of the new building system/product? (Please specify.) $2.80 U.S. Dollars/sq ft. unit

What developments do you foresee of your products in the near future? A pump to install the mortar into the brick joints.

Please send any brochures and information on your new building systems/products.

Appendix II. References

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