Evaluation of New Building Technology

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Abstract: This paper presents a proposed system for evaluating the expected utility of a new building technology and for aiding the decision-maker in making an appropriate and logical decision in implementing a new building technology. The developed evaluation system is a three-part approach consisting of technical-, economic-, and risk-assessment phases. An overall assessment factor (OAF) is determined, which provides a measure of the potential utility of the new technology. The technology index (TI) can also be determined, which expresses the expected utility of an evaluated technology relative to an existing or comparable technology. Four possible outcomes can result from the evaluation, ranging from large-scale implementation to discarding the technology from further consideration. Decision aids, including a decision nomograph and a decision flow chart, were developed to aid the decision-maker in determining the appropriate implementation decision based on evaluation results. An example application of the proposed evaluation methodology applied to a new exterior closure technology is provided.

Introduction

The continuing demand for more complex facilities, the advancement of technologies in other industries, the eroding competitiveness in the world market, and the increasing presence of foreign contractors have triggered the search for construction technology innovation in the United States (Halpin 1989). This "market push" and "technology pull" are challenging the U.S. construction industry, as well as academia, to find better ways to promote, transfer, and implement innovative construction technologies (Tatum 1987, 1989).

Many potential users (e.g., owners, constructors, etc.) of innovative technologies in the U.S. construction industry currently have no formal system for evaluating innovative construction technologies for potential implementation into their construction programs (Ioannou 1987). The adoption of a systematic technology evaluation system would place these entities in a proactive mode rather than a reactive mode in regard to implementation of innovative construction technologies (Napier 1987).

Research was performed at Purdue University to address the issue of how to systematically evaluate innovative construction technologies and to provide meaningful assessment parameters to users. The objectives of the research were:

1. To develop a comprehensive evaluation system for assessing the expected overall utility of a new building technology.
2. To construct decision aids to assist the decision-maker in making an ap-

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propriate decision in regard to the implementation of a new building technology.

3. To demonstrate the developed comprehensive evaluation system and decision aids through use of an example application of a new exterior closure technology.

The purpose of this paper is to present the results and findings of this research effort. This paper will begin with some background information on previous research performed by Purdue University researchers involving the identification and preliminary screening of new building technologies. The background will be followed by a description of the proposed methodology for the technical, economic, and risk assessment phases of the comprehensive evaluation system. An approach to calculating assessment parameters that will provide a measure of the overall utility of the evaluated technology is then discussed. An example application of the comprehensive evaluation system and decision aids using a new exterior closure technology (e.g., stone veneer finishing panels) will be presented throughout the paper. Finally, some guidelines on the use of the proposed evaluation methodology, conclusions drawn from the research, and recommendations for future research will be presented.

The reader should be advised that the terms "new," "emerging," and "innovative" are used interchangeably in this paper. A new, emerging, or innovative technology may refer to a material, product, method of construction, or management concept. The stone veneer finishing panel technology used as an example application is a natural stone veneer bonded by epoxy-impregnated glass fiber to an aluminum honeycomb panel. The term "building system" is used in this paper in a generic sense (e.g., substructure, superstructure, roofing, exterior closure, interior construction, mechanical, electrical, etc.).

Although an exterior closure technology is used in the example application, the reader should keep in mind that the developed generic framework for the evaluation methodology can be easily adapted for the evaluation of technologies for all building systems.

Background

Two research projects have been conducted by Purdue University to develop the framework for an overall building technology identification and evaluation (BTIE) system. The major steps of the developed BTIE system are shown in Fig. 1. Methods for performing the initial technology identification step shown in Fig. 1 was developed in the first research project (Hancher 1987; Chang 1988). The previously developed identification methodology consisted of information-gathering techniques, including a literature search, advertisements, telephone interviews, expert banks (e.g., professional experts), and a questionnaire survey.

The technology assessment guidelines from the first research project included an impact factor (i.e., percentage impact on the owner's construction program), a cost/benefit rating, and a level of risk, which were modified and relabeled as the preliminary screening step. This step facilitates the quick "weeding out" of technologies that would definitely provide the owner with little or no benefit. A detailed discussion of this preliminary screening meth-

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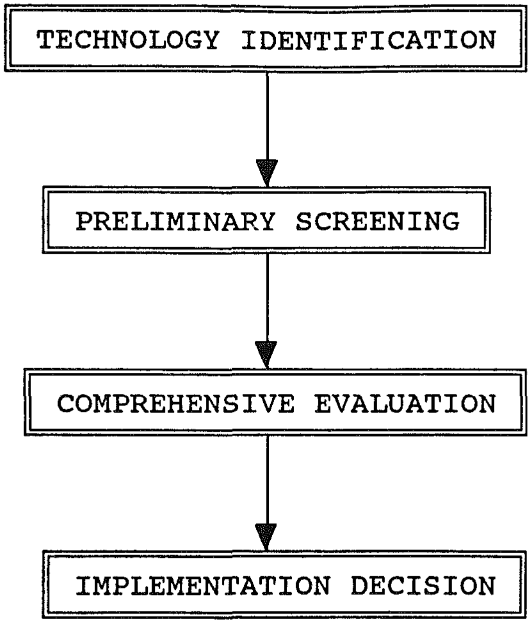

FIG. 1. Schematic Framework of Developed Building Technology Forecast and Evaluation System

odology is beyond the scope of this paper. Readers should refer to Chang (1988) for additional information.

Methodologies developed for the comprehensive evaluation and implementation decision steps were developed in the second research project and are the primary focus of this paper.

Technical Assessment

The first phase of the proposed three-phase comprehensive evaluation system is the technical assessment phase. The technical assessment methodology is based on the hypothesis that the technical performance of all building systems can be described by the following eight technical attributes: (1) Structural serviceability; (2) fire safety; (3) habitability; (4) durability; (5) practicability; (6) compatibility; (7) maintainability; and (8) architectural function. [Similar evaluation schemes have been developed (Rosen 1979; Ali 1987).]

Each of the eight technical attributes can be broken down into numerous subattributes. For example, fire safety can be broken down into fire resistance, combustibility, flame spread, smoke developed, toxicity, etc.

Evaluation Scheme

Generic technical evaluation schemes can be developed to evaluate new technologies for each major building system. Each evaluation scheme will consist of a technical attribute matrix (e.g., list of pertinent technical subat-

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ATTRIBUTE (1)	SUBATTRIBUTE (2)	SUBSYSTEM (3)				
		F	W	I	D	G
1. Structural Serviceability	1.1 Wind Resistance		X		X	X
	1.2 Seismic Resistance		X		X	X
	1.3 Impact Resistance	X	X			
	1.4 Indentation Resistance	X	X			
	1.5 Collapse Safety		X			
2. Fire Safety	2.1 Fire Resistance/Endurance	X	X	X	X	X
	2.2 Combustibility	X	X	X	X	
	2.3 Flame Spread	X	X	X	X	
	2.4 Smoke Developed	X	X	X	X	
	2.5 Toxicity	X	X	X	X	X
3. Habitability	3.1 Air Infiltration	X	X		X	X
	3.2 Ventilation					X
	3.3 Optical Properties	X	X		X	X
	3.4 Thermal Resistance		X	X	X	X
	3.5 Water Resistance	X	X	X	X	X
	3.6 Sound Absorption	X	X	X	X	X
	3.7 Insect/Rodent Resistance	X	X		X	X
	3.8 Forced-Entry Resistance				X	X
	3.9 Material Safety	X	X	X	X	X
4. Durability	4.1 Absorption-Freeze-Thaw	X	X	X	X	X
	4.2 U-V Radiation Resistance	X				
	4.3 Adhesion of Coatings	X				
	4.4 Wear/Abuse Resistance	X	X		X	X
	4.5 Deterioration Resistance	X	X	X	X	X
5. Practicability	5.1 Transportation Limitations	X	X	X	X	X
	5.2 Handling Limitations	X	X	X	X	X
	5.3 Field Tolerances	X	X	X	X	X
	5.4 Connections	X	X	X	X	X
6. Compatibility	6.1 Adherence of Sealants	X	X		X	X
	6.2 Corrosion Resistance	X	X			
7. Maintainability	7.1 Repairability	X	X	X	X	X
	7.2 Cleanability	X			X	X
8. Architectural Function	8.1 System Integration	X	X	X	X	X
	8.2 Appearance	X			X	X
	8.3 Privacy from Outdoors		X			X
	8.4 Vision of Outdoors		X			X

[1] Subsystem abbreviations: F-Finish, W-Wall, I-Insulation, D-Door, and G-Window

FIG. 2. Exterior Closure Technical Attribute Matrix

tributes for a particular building system) and descriptions of the pertinent technical subattributes. Technical evaluation schemes for the major building systems can be developed by consulting with building code organizations and other experts and by perusing owner requirements.

The technical attribute matrix for the exterior closure building system example application is shown in Fig. 2. In Fig. 2, all relevant technical subattributes for a nonbearing exterior closure system are listed, and the technical subattributes that should be evaluated for each subsystem (e.g., finish, wall, insulation, door, and window) during the technical assessment phase are marked with an X. For example, the stone veneer finishing panel technology consists of the finish and wall subsystems, so only the technical subattributes that are relevant to these two subsystems were evaluated.

Each attribute description contains sections on attribute significance, measurement, code criteria, and owner requirements. The significance section desccribes the importance and scope of the subattribute. The measurement section describes how the attribute is tested and measured. The code criteria section summarizes widely accepted building code standards from the International Conference of Building Officials (ICBO) Uniform Building Code, the Southern Building Code Congress International, Inc. (SBCCI) Standard Building Code, the Building Officials and Code Administrators International (BOCA) Basic Building Code, etc. The owner requirements section summarizes the owner's acceptance standards for the technical performance of the subattributes.

An owner who adopts the proposed methodology can develop an evaluation booklet for each major building system to be used by the designated evaluator(s). A building system evaluation booklet consists of a technical attribute matrix, the evaluation scheme, and all necessary worksheets to perform the comprehensive evaluation. The evaluator can determine which technical subattributes are relevant to the particular building technology by using the technical attribute matrix.

Once familiar with the relevant technical subattributes for a technology to be evaluated, the evaluator will refer to the technical attribute worksheets in the comprehensive evaluation booklet. The evaluator needs to prepare a technical attribute worksheet for each of the eight technical attributes. A sample technical attribute worksheet from the stone veneer finishing panel technology example application is shown in Fig. 3.

Technical Assessment Worksheet

As shown in Fig. 3, the subattribute name, owner requirements, and building code criteria are presented in columns 1, 2, and 3, respectively. The actual performance and technical comments on the technology are presented in columns 4 and 5, respectively. Actual performance of the technology can be determined through the U.S. Patent Office, building code organization evaluation reports, laboratory test results, and actual installed performance.

The user comments, subattribute rating, weighting factor, and weighted ratings are presented in columns 6, 7, 8, and 9, respectively. To rate each technical subattribute, the evaluator compares the actual performance of the evaluated technology, technical comments, and user comments with the owner requirements and code criteria. Technical comments can be obtained by consulting experts familiar with the technology type, and user comments can be obtained by contacting owners, architectural/engineering (A/E) firms, construction managers, constructors, and end-users of the technology. The evaluator makes a qualitative assessment of the performance of the technical subattribute and assigns one of the following six available ratings:

3 = Actual performance exceeds owner requirements
2 = Actual performance is comparable to owner requirements
1 = Actual performance is less than owner requirements
X = Actual performance is unacceptable
I = Insufficient information to make rating
N = Not relevant for technology being evaluated

It should be noted that the assignment of an X rating to the technical performance of an attribute does not automatically reject the technology at

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Building System Evaluation Scheme: Exterior Closure

Building Technology Evaluated: Stone Veneer Finishing Panels

Attribute No: 2 Name of Attribute: Fire Safety

Subattribute (1)	Owner Requirements for Building System (2)	Code Requirements for Building System (3)	Actual Performance of Technology (4)	Technical Comments on Technology (5)	User Comments (6)	Rating (7)	Weighting Factor (8)	Weighted Rating (9)
2.1 Fire Resistance & Endurance	Nonbearing walls must have a 4 hr. rating. Openings must have a 3/4 hr. rating. Refer to attribute description for exceptions.	Nonbearing walls must have a 4 hr. rating. Openings must have a 3/4 hr. rating.	No fire resistive rating.	Refer to technical comment for 2.2 below.	No problems reported.	1	0.263	0.263
2.2 Combustibility	Noncombustible materials shall be used. Exceptions do exist for Type III-N and Type V-N construction.	Noncombustible materials shall be used with the exception of fire retardant wood.	Potential heat of combustion of 1,150 Btu/lb. (4,000 Btu sq. ft.)	Approved for use in noncombustible wall construction Passed the UBC 17-6 Multistory Fire Test.	No problems reported.	2	0.204	0.408
2.3 Flame Spread	FSI must not exceed 50 for family housing and 75 for other. FSI for insulation between wall assemblies shall not exceed 100.	Building codes only address interior construction.	Flame Spread Classification of 10.	Product is suitable for NFPA Class A or UBC Class I.	No problems reported.	3	0.217	0.651
2.4 Smoke Developed	Smoke Developed Rating must not exceed 150. Rating can be waived for insulation between wall assemblies.	None	Smoke Density Class of 195	Product is suitable for NFPA Class A or UBC Class I	No problems reported.	2	0.172	0.344
2.5 Toxicity	None	None	Toxicity test has been performed but results were not available.	None	No information.	I	N/A	-----
					Subtotals		0.856	1.666
					Attribute Score = 1.666 / 0.856 = 1.95			

3 = Actual performance exceeds owner requirements
2 = Actual performance is comparable to owner requirements
1 = Actual performance is less than owner requirements

X = Actual performance is unacceptable
I = Insufficient information to make rating
N = Not relevant for technology being evaluated

FIG. 3. Sample Technical Assessment Worksheet

this point, but merely serves as a flag for the evaluator to consider this deficiency later in the evaluation process. It may be possible to easily overcome the deficiency of an unacceptable attribute of an otherwise acceptable technology through modification or other means, and it would be premature to reject the technology during the technical assessment phase. For example, it might be possible to change an untreated timber framing technology with unacceptable fire safety attributes into an acceptable technology by using fire retardant treatment.

Weighting factors to adjust for the relative importance of the subattributes can be determined by polling a large sample of in-house and/or outside experts and having them rate the relative importance of technical subattributes for each of the eight technical attributes for each building system, with the sum of all weighting factors for each attribute equaling 1.00. For the example application, weighting factors have been assigned by the writers to demonstrate the proposed methodology.

The weighted subattribute ratings are determined by multiplying the subattribute rating by the assigned weighting factor. The sum of the weighted ratings for the subattributes for a particular attribute is the attribute score for that attribute. The attribute score given in Fig. 3 for fire safety is 1.95. Since this score is slightly less than two, it indicates that the overall fire safety performance for the stone veneer finishing panel is expected to be slightly less than owner requirements. An attribute score larger than two would have indicated that the expected performance of the attribute exceeds owner requirements.

In Fig. 3, the weighting factor for toxicity has not been included in the weighting factor subtotal for calculating the attribute score because the subattribute received an I rating. A subattribute that receives an X rating is assigned a zero-weighted rating, and its weighting factor is included in the weighting factor subtotal for calculating the attribute score.

After determining the attribute scores for all eight attributes, the evaluator prepares a technical assessment summary sheet as shown in Fig. 4. The summary sheet is just a recap of the attribute scores for the eight technical attributes. Again, weighting factors can be used to adjust for the relative importance among the technical attributes.

The TAF (technical assessment factor) is calculated by the following equation:

$$\mathrm{TAF} = \frac{\sum_{i=1}^{n} W_i A_i}{2} \quad (1)$$

where A_i = attribute scores; and W_i = attribute weighting factors.

The TAF value of 1.03 for the stone veneer finishing panel indicates that the technical performance of the technology is expected to be slightly better than owner requirements.

As shown in Fig. 4, any deficient, unrated, and unacceptable subattributes should be itemized. The evaluator should prepare a brief disposition report on each of the deficient and unrated subattributes describing their potential effect on the technical performance of the technology.

Economic Assessment

The second phase of the proposed three-phase comprehensive evaluation

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Building System: Exterior Closure

Building Technology: Stone Veneer Finishing Panels

Attribute (1)	Score (2)	Weighting Factor (3)	Weighted Score (4)
1. Structural Serviceability	2.03	0.175	0.355
2. Fire Safety	1.95	0.159	0.310
3. Habitability	2.00	0.138	0.276
4. Durability	2.56	0.127	0.325
5. Practicability	2.23	0.091	0.203
6. Compatibility	1.00	0.114	0.114
7. Maintainability	2.44	0.087	0.212
8. Architectural Function	2.45	0.109	0.267
Subtotals		1.000	2.062

Technical Assessment Factor (TAF) = 2.062 / 2(1.000) = 1.03

Deficient Subattributes (5)	Rating (6)
1.3 Impact Resistance	1
2.1 Fire Resistance/Endurance	1
6.1 Adherence of Sealants	1

FIG. 4. Sample Technical

system is the economic assessment. The economic assessment worksheet prepared for the stone veneer finishing panel example application is shown in Fig. 5.

Life Cycle Cost Analysis

The objective of the economic assessment phase is to determine the estimated life cycle costs for the new technology and for a comparable subsystem basis, including installed cost, maintenance cost, and miscellaneous economic adjustments (e.g., energy efficiency, etc.). The subsystem basis should be an existing technology that is currently being used by the owner to provide consistent values when multiple technologies are being evaluated for the same building system. This subsystem basis is a base alternative that can be compared to the estimated cost of the new technology to estimate

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Subattributes Not Rated Due To Insufficient Information (7)	Unacceptable Subattributes (8)
1.4 Indentation Resistance 1.5 Collapse Safety 2.5 Toxicity 3.4 Thermal Resistance 3.6 Sound Absorption 3.7 Insect/Rodent Resist. 3.9 Material Safety	None

Disposition of Deficient, Unrated, and Unacceptable Subattributes (9)
1.3 Impact Resistance: Some fine cracks occurred when subjected to impact testing but technology outperforms conventional stone construction.
1.4 Indentation Resistance: Unrated but no problems have been reported.
1.5 Collapse Safety: Unrated but failure of assembly is not expected to lead to a catastrophic failure of the building.
2.1 Fire Resistance/Endurance: Unrated but has been approved for uses in noncombustible wall construction by ICBO.
2.5 Toxicity: Unrated but no problems have been reported. Little research has been done in this area.
3.4 Thermal Resistance: No information available but the honeycomb core panel should provide some thermal resistance benefit.
3.6 Sound Absorption: Unrated but appropriate selection of insulation for wall section should satisfy and sound absorption requirements.
3.7 Insect/Rodent Resistance: No information available but should be insect/rodent proof if joints are caulked properly.
3.9 Material Safety: Unrated but no problems have been reported.
6.1 Adherence of Sealants: One contractor reported problems but the technology has performed well under accelerated aging, infiltration, and permeability testing.

Assessment Summary Sheet

the potential savings (or loss) that should be realized by implementing the new technology. In the example application shown in Fig. 5, the cut stone-steel truss exterior wall system was used as the subsystem cost basis.

As shown in Fig. 5, the installed cost and annual maintenance cost are estimated for both alternatives. The life expectancies of the innovative technology and the subsystem basis are then determined. In the example provided, 25-yr-life expectancies were used for the new and alternative technologies since their life expectancies exceeded the facility life of 25 years. Capital recovery factors for both alternatives are determined using the owner's economic criteria. For the example application, a 25-yr facility life and a 10% discount rate were used. The initial cost for each alternative is then converted into an annual cost using the appropriate capital recovery factor. These annual costs are added to the estimated annual maintenance costs to

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Building Technology: Stone Veneer Finishing Panels

Subsystem Cost Basis: Cut Stone - Steel Truss Exterior Wall Sys.

Facility Life: 25 years   Discount Rate: 10 percent

Case	Initial Cost ($/sf) (1)	Life (yrs) (2)	Capital Recov. Factor (3)	(1)*(3) Initial Cost ($/sf/yr) (4)	Maint. Cost ($/sf/yr) (5)	(4)+(5) Life Cycle Cost ($/sf/yr) (6)
Subsystem Cost Basis	31.50	25+	0.1102	3.47	0.50	3.97
Estimated for New Technology	25.75	25+	0.1102	2.84	0.50	3.34

Calculations
(7)

$$\text{Savings Assessment Factor (SAF)} = 2 - \frac{\text{Technology Life Cycle Cost}}{\text{Basis Life Cycle Cost}}$$

$$= 1.16$$

Estimated Unit Savings = Subsystem Total Unit Cost less Technology Total Unit Cost

= $0.63 per square foot per year

Projected Savings = Impact Factor[1] * (SAF - 1) * Estimated Construction Budget

= 0.005 * 0.16 * $100,000,000

= $80,000

[1]Impact Factor is the estimated percentage impact of the technology on the owners construction budget.

Calculation Notes
(8)

(1) The installed cost of $29.00/sf for the stone panel technology has been adjusted to account for an approximate $3.25/sf savings which can be achieved through a lighter superstructure and foundation. The A-E must design a lighter structure for this savings to be realized.

(2) Savings realized from using this technology are generally higher for larger buildings and buildings with a steel superstructure than for smaller buildings and buildings with a reinforced concrete superstructure.

(3) A potential savings can be realized in shipping and handling of the lighter weight material.

(4) The technology and the system cost basis are both virtually maintenance free since they are of stone construction. Expected maintenance consists of annual inspections, occasional caulking repair, and occasional cleaning.

FIG. 5. Sample Economic Assessment Worksheet

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determine the equivalent uniform annual costs for the innovative technology and the subsystem cost basis.

Savings Assessment Factor

The savings assessment factor (SAF) can then be determined by using the following equation:

$$\text{SAF} = 1 + \underset{\text{(decimal)}}{\text{Percent Savings}} = 2 - \frac{\text{Technology Total Unit Cost}}{\text{Basis Total Unit Cost}} \quad \ldots\ldots\ldots\ldots (2)$$

Calculations can also be made to determine the estimated unit savings (or loss) and the projected total savings (or loss) that should result if the technology were implemented. Projected savings assuming full implementation of the new technology can be calculated by using the following equation:

$$\text{Projected Savings} = \text{Impact Factor} \times (\text{SAF} - 1) \times \text{ECB} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

where ECB = estimated construction budget.

The impact factor is a parameter that describes the potential impact of the technology on the owner's building program and can be determined by estimating the percent of the owner's forecasted construction budget that includes the building system(s) to be provided by the technology. A detailed methodology for determining the impact factor is given by Chang (1988).

As shown in Fig. 5, the SAF of 1.16 for the stone veneer finishing panel indicates that an estimated savings of 16% and an estimated annual unit savings of \$0.63 could be realized by implementing the new technology. If an owner has an estimated construction budget of \$100,000,000 and an impact factor of 0.5%, an estimated savings of \$80,000 could be realized by fully implementing the new technology into the given construction program over the budget term.

Any additional economic criteria that should be considered by the decision-maker when considering use of the innovative technology should also appear as notes at the bottom of the economic worksheet. Comments may be required to describe fluctuations in expected savings due to other factors such as economies of scale, types of construction being used for other building systems, and geographic variability in material availability and costs, etc.

Risk Assessment

The third phase of the proposed three-phase comprehensive evaluation system is the risk assessment phase. The risk assessment worksheet for the stone veneer finishing panel is shown in Fig. 6.

As shown in Fig. 6, the risk assessment worksheet lists ten evolutionary steps of technology development from "innovation is based on sound design" to "innovation is in wide use." A probability of success can be assigned to each risk level based on the risk management philosophy of the user. The probability of success is the probability that the technology will perform as predicted by the TAF. The plot of probability of success versus risk level is expected to be a unique curve for each building system or subsystem. The evaluator can determine the probabilities of success for each

Technology Evaluated: Stone Veneer Finishing Panels

Risk Level (1)	Description (2)	Probability of Success (3)
9	Innovation is based on sound design	0.50
8	Test models have been developed	0.56
7	Full scale version has been constructed	0.61
6	Technology has been commercially installed	0.67
5	There have been more than ten commercial installations	0.72
4	Innovation has been accepted into a local building code	0.78
3	Innovation has been accepted by one of the three major building code organizations	0.83
2	Innovation has been accepted by at least 2 of the 3 major building code organizations	0.89
1	Multiple suppliers for the innovation exist	0.94
0	Innovation is in wide use	1.00

Risk Assessment Factor (RAF) = Probability of Success = 0.89

FIG. 6. Sample Risk Assessment Worksheet for Exterior Closure Technologies

risk level for all building systems, or subsystems, by polling a large sample of in-house and/or outside experts. For the example application shown in Fig. 6, probabilities of success were assigned to the various risk levels by the writers to demonstrate the developed methodology.

The risk assessment factor (RAF) is equivalent to the probability of success for the technology. In the example application, the risk level is two because the technology has been accepted by two of the major building code organizations, but multiple suppliers for the technology do not exist. The probability of success corresponding to risk level two for an exterior closure system is 0.89. Therefore, the RAF is 0.89 for the stone veneer finishing panel technology.

Overall Assessment

The objective of the overall assessment is to determine parameters that provide a measure of overall attractiveness or utility of the evaluated technology and to summarize the results of the comprehensive evaluation in a condensed format for the decision-maker.

Overall Assessment Factor

Once the TAF, SAF, and RAF have been determined, an overall assessment factor (OAF) is calculated as follows:

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Building Technology: Stone Veneer Finishing Panels

Technology Index	=	1.04
Overall Assessment Factor (OAF)	=	1.06

A. Impact Factor	=	0.5%
B. Technical Assessment Factor (TAF)	=	1.03
C. Savings Assessment Factor (SAF)	=	1.16
D. Risk Assessment Factor (RAF)	=	0.89
E. Estimated Annual Unit Cost Savings	=	$0.63/SF
F. Estimated Total Potential Savings[1]	=	$80,000
G. Technical Attribute Scores:		
1. Structural Serviceability	=	2.03
2. Fire Safety	=	1.95
3. Habitability	=	2.00
4. Durability	=	2.56
5. Practicability	=	2.23
6. Compatibility	=	1.00
7. Maintainability	=	2.44
8. Architectural Function	=	2.45
H. Deficient Subattribute Ratings:		
1.3 Impact Resistance	=	1
2.1 Fire Resistance/Endurance	=	1
6.1 Adherence of Sealants	=	1

I. Unacceptable Subattribute Ratings:

None

J. Unrated Subattributes:

1.4 Indentation Resistance	1.5 Collapse Safety
2.5 Toxicity	3.4 Thermal Resistance
3.6 Sound Absorption	3.7 Insect/Rodent Resist.
3.9 Material Safety	

[1]Estimated Total Potential Savings is based on 100 percent utilization of the new technology over the budget term.

FIG. 7. Sample Comprehensive Evaluation Summary Report

$$OAF = (RAF) \times (TAF) \times (SAF) \quad (4)$$

The OAF is an overall measure of the estimated utility or benefit of the technology. A technology that has a TAF = 1 (i.e., technical performance is comparable to owner requirements), an SAF = 1 (i.e., cost of technology is the same as that of the system cost basis), and an RAF = 1 (i.e., there is essentially no risk because the technology is in wide use) would have an OAF of one.

In general, a technology with an OAF greater than one may be a promising technology and should be considered for implementation. A technology with an OAF less than one should probably be eliminated from the BTIE cycle by the decision-maker. As shown in the comprehensive evaluation summary report shown in Fig. 7, the stone veneer finishing panel has the potential for being a promising technology because it has an OAF of 1.06.

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Technology Index

An overall assessment factor (OAF) can be calculated for both the new technology and for an existing technology to allow for a direct comparison between a proposed alternative and a base alternative. This comparison can be directly expressed by the technology index (TI) of the evaluated technology, which is defined as follows:

$$\mathrm{TI} = \frac{\mathrm{OAF}_p}{\mathrm{OAF}_E} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

where OAF_p = OAF for the proposed technology; and OAF_E = OAF for the existing technology.

The OAF_E is also determined by using Eq. 4. The SAF of the existing technology will always be one since it is also the base alternative and is compared to itself. However, the TAF and the RAF of the existing technology are not necessarily one and must be determined using the prescribed methodologies.

In general, only technologies with a TI approximately equal to or greater than one should be considered for implementation. If the OAF of the comparable technology used for comparison purposes in the example application is 1.02, then the TI for the evaluated technology would be an acceptable value of 1.04.

As shown in Fig. 7, the comprehensive evaluation summary report contains the TI, OAF, impact factor, TAF, SAF, RAF, estimated cost savings, a recap of attribute scores for the eight technical attributes, and a listing of any deficient, unrated, or unacceptable subattribute ratings. The listing of deficient, unrated, and unacceptable subattributes serves as a flag to the decision-maker to refer to the disposition comments for these subattributes contained in the technical assessment summary sheet.

Implementation Decision

After being presented with the comprehensive evaluation summary report and supporting worksheets for an emerging and/or innovative building technology during a BTIE cycle (i.e., periodic review of technology evaluation and performance results), the decision-maker(s) must determine the appropriate course of action.

Decision Alternatives

The four potential outcomes of the comprehensive evaluation in regard to implementing a new technology are:

1. Eliminate technology from BTIE program.
2. Reconsider technology next BTIE cycle.
3. Conduct trial implementation of the technology.
4. Consider a large-scale implementation of the technology.

The actual performance of a technology that is implemented on a trial basis should be closely monitored. If the trial implementation of the evaluated stone veneer finishing panel technology is unsatisfactory, no additional implementation should be conducted unless warranted in a subsequent BTIE cycle. If the trial implementation of the stone veneer finishing panel technology is satisfactory, then a large-scale implementation may be considered. Use of this technology should continue until it is superseded by a superior technology.

Decision Analysis

During a BTIE cycle, the decision-maker(s) must decide what action should be taken. A decision based solely on a single parameter such as TI or OAF may not necessarily be a good one. For example, a technology may have a high OAF (e.g., above one), but the OAF of the existing technology may be higher. Additionally, a technology may have a high TI (e.g., above one) but may also have a low SAF. It is obvious that the decision-maker must carefully consider all of the information provided on the comprehensive evaluation summary report to make an appropriate decision. The decision-maker may also need to refer to the supporting worksheets to peruse additional details or technical comments on deficient technical subattribute scores.

It may be helpful for the decision-maker to establish various criteria or guidelines for determining which new technologies should be considered for implementation and for determining which ones should not be considered. One method for accomplishing this may involve the development of rules consisting of lower bounds for evaluation parameters such as TI, OAF, TAF, RAF, and SAF. A sample set of decision rules that could be used to aid the decision-maker is presented as follows:

1. If OAF < 1, eliminate technology from the BTIE program. Otherwise, proceed to rule 2.
2. If TI < 1 or any technical subattributes are unacceptable, reconsider technology during the next BTIE cycle. Otherwise, proceed to rule 3.
3. If SAF < 1 and TAF < 1, then conduct a trial implementation of the technology. Otherwise, proceed to rule 4.
4. If RAF > 0.95, then consider conducting a large-scale implementation.

Decision Aids

Decision criteria can also be presented in the form of decision aids to assist the decision-maker. Two types of decision aids were developed—a decision nomograph and a decision flow chart.

As shown in Fig. 8, the ordinate axis of the decision nomograph is graduated in terms of TAF $\times$ RAF on the left side of the nomograph and is graduated in terms of OAF on the right side. The abscissa axis is graduated in terms of SAF and percent savings on the bottom and top of the nomograph, respectively. The percent savings scale has been added as an additional parameter primarily for the benefit of upper management who will certainly be concerned with the potential economic benefit of the new technology but may not fully appreciate the meaning of the SAF. Lower acceptability bounds have been established at 0.9 for TAF $\times$ RAF and for SAF. The nomograph has been divided into several different acceptance regions by these boundary lines as shown in Fig. 8. The plot of the stone veneer finishing panel technology falls in the trial implementation acceptability region of the nomograph.

As shown in Fig. 9, the decision flow chart is a graphical presentation of the four previously discussed decision rules. The decision-maker inputs the

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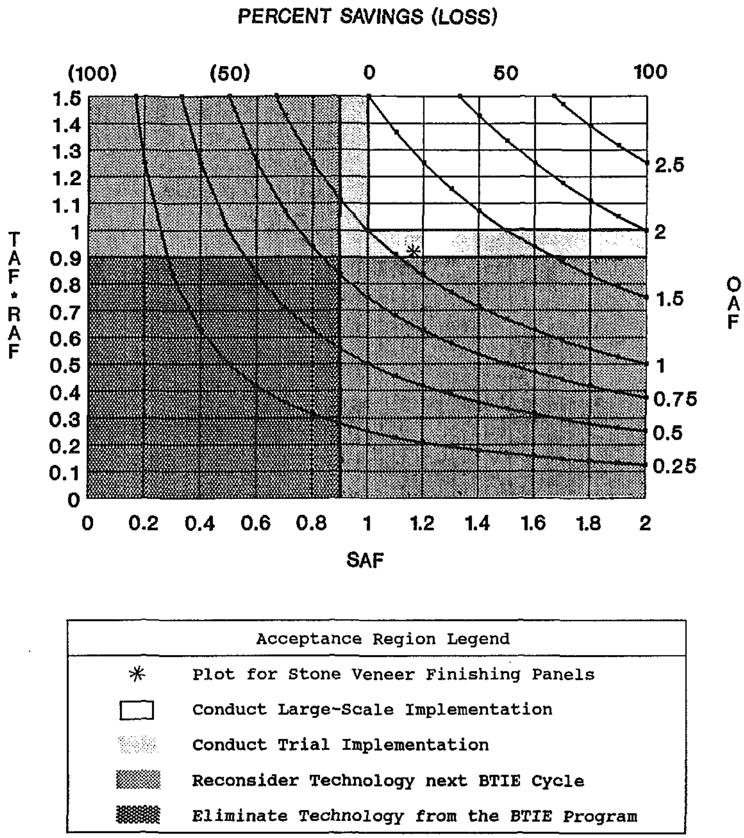

FIG. 8. Decision Nomograph

values for OAF, TI, SAF, TAF, and RAF, and then starts at the top of the flow chart and progressively moves down through the decision points on the flow chart until the appropriate decision is reached. Using the decision flow chart shown in Fig. 9, the decision-maker would also determine that the appropriate recommendation for the stone veneer finishing panel technology is to conduct a trial implementation.

The decision nomograph and decision flow chart presented will not always produce identical results since the TAF and RAF are treated as a product in the nomograph instead of individual parameters as in the flow chart.

Use of Proposed Evaluation Methodology

The proposed methodology consists of a flexible, generic evaluation system that can be used to evaluate new technologies for all types of building systems. Due to the emphasis placed on simplicity in designing the evaluation methodology, the user should be aware that the evaluation system does contain some subjectiveness. It should be kept in mind that the intent of the various evaluation parameters is to provide comparative indicator values for

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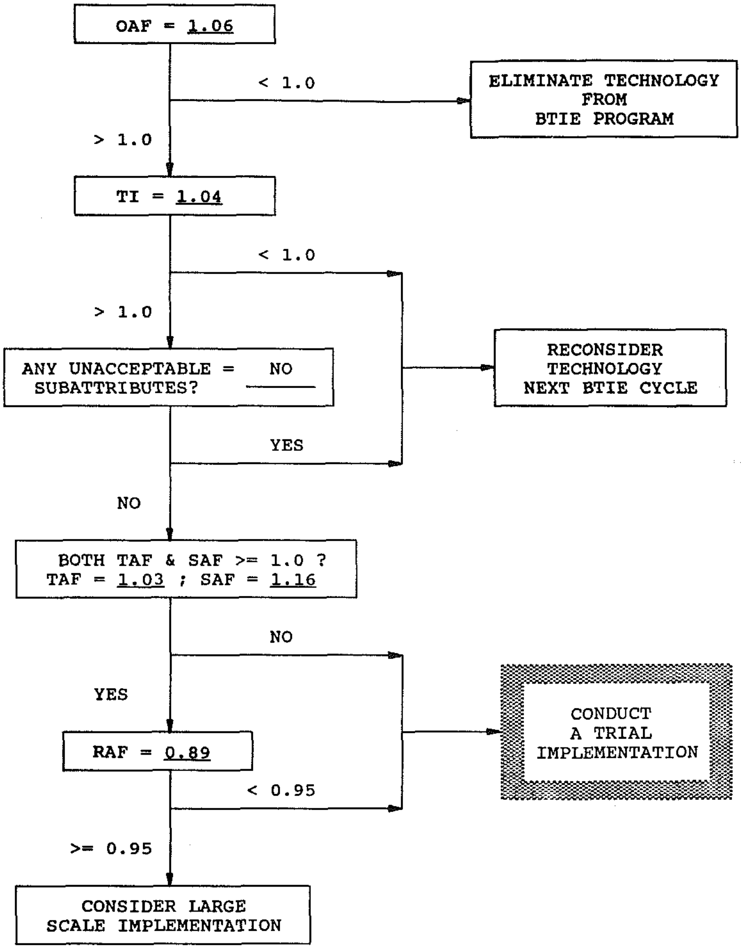

FIG. 9. Decision Flow Chart

the expected utility of a new technology and not to provide absolute values. Where possible, evaluations should be performed by the same group of designated evaluators to promote consistent administration of the methodology.

The final evaluation results (e.g., OAF and TI) were found to be virtually insensitive to the technical subattribute weighting factors and only moderately sensitive to the technical attribute weighting factors and to the risk level probability of success values. The level of confidence of these parameters can be enhanced through statistical determination of their values by polling a large sample of experts.

Validity checks performed on the assignment of the technical attribute scores indicated low variability due to the simplicity of the rating scheme. Since the rating scheme consists of only six easily distinguishable rating parameters (i.e., 3, 2, 1, X, I, and N), very little subjectivity enters into the decision-making used to assign the appropriate ratings. The validity of impact factors used during the evaluation is dependent on the precision used by the owner in forecasting his future construction budget and in estimating the utilization potential of the new technology.

Conclusions and Recommendations

Many potential users of new building technologies in the construction industry currently have no systematic methodology for adopting technological innovation into their building programs. The proposed building technology evaluation system should aid potential users in their efforts to make appropriate decisions in regard to the potential use of new building technologies based on systematic procedures and engineering judgement.

Three recommended areas for future research include the development of technical evaluation schemes for other building systems, the development of a more numerically objective decision analysis framework for implementation of innovative technologies, and full automation of the proposed management system.

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