IMPLEMENTING CONSTRUCTION INNOVATIONS

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The need to gain a competitive advantage stimulates many construction organizations to exploit innovative products and processes. The high level of uncertainty associated with innovative construction leads many construction organizations to focus on the application of traditional construction processes and products. Implementing construction innovation often involves experimentation, iteration and refinement of activities that are reliant on volatile information. Although several decision support models have been developed to assess new technologies, innovation as an implementation process has received less attention. This paper presents several tools to assess the value of technological innovation. It also presents a conceptual model, which is currently being developed, that deals with the effectiveness of innovation implementation phase. The proposed model is a decision support tool that models different implementation scenarios. The model uses influence information, managerial and technological benefits to control the implementation phase.

Keywords: construction innovation, decision-making, performance assessment.

INTRODUCTION

Construction innovation is the process through which new ideas turn into new components of a constructed product that has economic, functional or technological value. The new components may revolutionize the process itself and result in traditional and accepted processes being replaced by new approaches that require deliberate and informed action and control.

The decision to adopt a new idea requires the consideration of many factors. Cost/benefit factors have to be evaluated along with risks and uncertainties. Truly, innovative ideas have little historical data to aid implementation and this increases the degree of uncertainty. Intangible benefits offered by advanced construction technologies are hard to quantify using traditional economic analysis techniques and this may result in the rejection of a potentially profitable idea.

Although several models have been developed to assess the performance of new technology, little attention has been paid to implementation. The implementation phase includes several steps at which decisions need to be analysed. According to Wakeman (1997), project development moves from the debate to action level where decision-makers face four potential barriers to success; namely, technical, financial, institutional and public/perceptual. A decision support tool that enables managers to successfully implement construction innovation in a structured way should control innovative activities and overcome these barriers. This paper presents a generic conceptual model that deals with the implementation phase of innovation and considers the assessment of its effectiveness.

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DECISION ANALYSIS

A decision has been defined as "the knowledge structure or set of expectations that an individual draws upon to guide interpretation, inference and action in any particular situation", Boland *et al.* (1990). Not all decisions are straightforward and many involve complex problems, which require detailed analysis if the best solution is to be determined. Decision analysis takes its scope not just from the comparative evaluation of alternatives, but the entire process that leads to complete description of the problem structure. This includes generating alternatives, modelling their probable impact, and assessing the preferences of individual decision-makers. The objective of decision analysis is not to select an optimum alternative but to provide insight about the problem and to promote creativity in dealing with it and commitment to the decision later, according to Ferrell (1994).

Decision analysis structure

In decision analysis, a problem is decomposed into elements small enough to be analysed. The possible events, decisions, uncertainties, expected outcomes and the relationships among them are then represented in a form of model. By determining the value of each possible group of events and estimating the probability of uncertain outcomes, decision-makers can evaluate intermediate points in the model and identify the sequence that will lead to the optimal results. Decision analysis is structured by the:

- formal tools of decision theory, probability theory and mathematical modelling;
- accumulated research findings in the area of behavioural judgement and decision-making; and
- skilled judgement of analysts and subject experts.

Typical sources of complexity within decision analysis, as listed by Keeney (1982) include:

- multiple objectives, not all of which can be achieved;
- difficulty in identifying good alternatives;
- the importance of intangible factors;
- long time horizons with effects extending far into the future;
- many groups being affected and concerns for equity;
- risk and uncertainty from many sources including the actions of others, changes in priorities over time and lack of data or inherent unpredictability;
- risks to health and safety;
- need for expert knowledge from multiple disciplines;
- multiple decision makers and stakeholders;
- significant value trade-offs;
- attitudes toward risk taking; and
- decisions being sequential, earlier ones conditioning those that follows.

Wright and Ayton (1994) stated that: a causal chain, linking problematic situations to events and actions, is established by decision-makers when simulating their perceptions of an innovation problem. This is firstly identified in terms of performance such as less quality. The root causes of this poor performance should be defined, for example quality control and so on. This indicates what direction a decision-maker needs to investigate to achieve innovation, why a response is necessary, how a set of possible actions can solve the problem, and how a course of these actions may be selected.

Techniques used to assess the performance of new technologies have started to shift away from the strict return-on–investment (ROI) evaluation, which can be seen as a tactical nature, to value-added concepts of strategic nature. The following sections present the decision techniques used to assess technological innovations.

Discriminant and classification techniques
Discriminant and classification analyses are multivariate techniques concerned with separating distinct sets of objects (or observations) and allocating new objects (or observations) to previously defined groups. Discriminant analysis is exploratory in nature and often used on a one-off basis in order to investigate observed differences when causal relationships are not well understood. Classification procedures are less exploratory in the sense that they lead to well-defined rules, which can be used to optimally assign a new object to the labelled classes. These two methods are not appropriate when the decision-maker does not know the value of an object attribute and may not have historical data as each problem is different, Murtaza (1993). Ioannou (1993) developed a computer database for classification, documentation, storage and retrieval of information about emerging construction technologies. These technologies are combinations of resources, methods and environmental requirements/constraints that constitute a construction product.

Subjective weighting factors technique
The subjective weighting factor technique was derived from decision analysis to model judgmental assessment. This can be achieved by identifying a weighting factor appropriate to the parameters used in the assessment. These weighting factors need to be tested periodically to ensure that they are realistic and balanced, Perkowski (1988). Lutz (1990) developed a comprehensive evaluation system for assessing the expected overall utility of a new building technology. In this system, a technical assessment phase is used to assess new technology by technical performance attributes. Technical evaluation of building systems can be developed through building code and owner requirements. The performance is determined by weighting factors to rate the relative importance of technical attributes for each building system. Another phase is the economic assessment. This is used to determine the estimated life cycle costs of the new technology to estimate the potential savings or loss. The third phase is the risk assessment. A risk assessment factor is a measurement by experts of the probability that the new technology will perform as required. By multiplying these three factors, an overall assessment factor can be determined.

Analytical Hierarchy Process (AHP)
The AHP approach agrees well with the behaviour of a decision-maker that bases judgements on knowledge and experience and provides a structured relatively simple solution to the decision-making problems. It organizes tangible and intangible factors that affect the decision in systematic levels. Each level contains elements of decision

alternatives. Pair-wise comparisons between elements at each level are made regarding their relative importance with respect to or impact on the elements at the adjacent upper level. The comparison is based on a level of importance on a scale of 1-9 and allocated in a comparison matrix, as suggested by Saaty (1980). Through the normalized eigenvalues of a comparison matrix, the relative strengths of its elements in aggregating a final evaluation can be determined. Skibniewski and Chao (1992) used the AHP technique to model the consistency of comparison of alternatives in the decision-making process of technology selection. This model comprises the overall assessment (level 1); 'Cost Factors' and ' Benefit Factors' (level 2) stand for the groups of favourable and unfavourable factors, respectively, reflecting the decision maker's general criteria for evaluation; the criteria in (level 3) are gradually specified and divided into more specific evaluation attributes which may be operational benefits, NPV, quality improvement or initial investment; and finally the alternative solutions occupy the lowest level. Through this analysis, the decision-maker can assess the new technology based on tangible and intangible factors.

AbouRizk *et al.* (1994) used the AHP technique to determine the relative importance of the criteria that affect decision-making to adopt innovations and the importance of the risk factors relative to each criterion. This process is repeated to evaluate the relative effect of risk factors on the alternatives resulting in a weighted matrix.

Trinh and Sharif (1996) suggested a list of attributes for assessing product and process complexity involved in construction. To determine the weighting of all attributes and quantify the values of qualitative attributes, Trinh and Sharif used the AHP. Technological production systems include both product and process aspects. The design and production processes that create a product need to be evaluated. The technological complexity of a construction process can be considered as the technological requirements that the construction process must meet if it is to convert a particular design effectively (with specifications) into an actual product. The technology level of a particular product is measured by a set of key attributes, such as the performance function while the process attributes may include the construction speed. Estimating the attribute value of each product and weighting this attribute for all attributes characterizes the complexity of a product. The larger the value of this estimation, the higher the complexity of the product. This can also be achieved for production processes.

A Neural Network based approach, which incorporates the AHP method, was proposed by Chao and Skibniewski (1995) for predicting the adoption potential or acceptability of a new construction technology. This approach: identifies technology performance factors (cost, risk, flexibility, manoeuvrability, and so on); selects the common choice for the considered operation as a base technology; produces performance characteristic vectors for alternative technologies using the AHP method; and determines acceptability of alternative technologies using the proposed NN model.

Simulation technique

Based on the role of 'champions', which is crucial to the successful implementation of most innovations, Schumacher *et al.* (1998) developed a training simulation tool to enhance the innovative capacity of these champions in mature organizations. This tool includes method to build interaction with information sources to achieve innovation and to solve problems that may arise during the innovation process.

A GENERIC CONCEPTUAL MODEL

However, the above decision tools have been developed to help managers in choosing among alternatives or in adopting a new technology, these tools have not considered innovation as a dynamic process and have not dealt with the implementation phase from a planning perspective. The proposed model is based on simulating this implementation phase.

This research presents a conceptual model that deals with the effectiveness of the innovation implementation phase. The proposed model is a decision support tool that models different implementation scenarios. The model uses influence information, and managerial and technological benefits to control the implementation phase. It is also designed to be used as a planning tool for the innovation implementation phase. This will help to define all situations of a particular innovation and improves monitoring the process of implementing innovation with its uncertain events. This planning tool can promote construction innovation where the most important characteristics of construction innovation, (i.e. high level of uncertainty and iterative nature of its activities), can be simulated and monitored.

Aspects that differentiate innovative projects from traditional ones are: more initial problems; longer preparation time; high initial cost; more training and changing in management tools and more changes and deviations. Refinement, experimentation and iterations to achieve a certain task or a group of tasks are required before final product acceptance. The combination of the dynamic environment and the nature of construction innovation result in a complex decision-making process. The dynamic environment is characterized by iterations between strategic decisions, marketing policies, production practices, regulations imposed by the government, and research and development priorities.

The higher level of uncertainty associated with construction innovation requires more frequent updating and shortening of the communication time between the sources of information and the focus of decision-making. It is vital that channels of communication should be established that enable project managers to see all that is relevant. Changes should be controlled and documented by evaluating decision nodes that improve the selection process for implementation and considering the iterative (loops) progressing.

A generic conceptual model describing the information affecting construction innovation and effectiveness measurement of its implementation is presented in this paper. The proposed model targets the decomposition of the innovation process into elements. The model, shown in Figure 1, demonstrates the involved changeable information that affects the decisions adopted by managers during the implementation phase of innovation. Links among the model elements describe the iterative characteristic of this process resulted from achieving each element.

Innovation objectives

Innovation objectives are the forces driving innovation and can be on a project or a strategic basis. These forces may include: problems that cannot be solved by current technologies; owner demands that are not only for safe and economic products, but also for more functional facilities and aesthetic criteria; and the strategic needs of an organization to gain competitive advantages. The high standard of regulatory demands may cause design and construction teams to innovate to fulfil these regulations. Changes in the construction environment, engineering, industry and

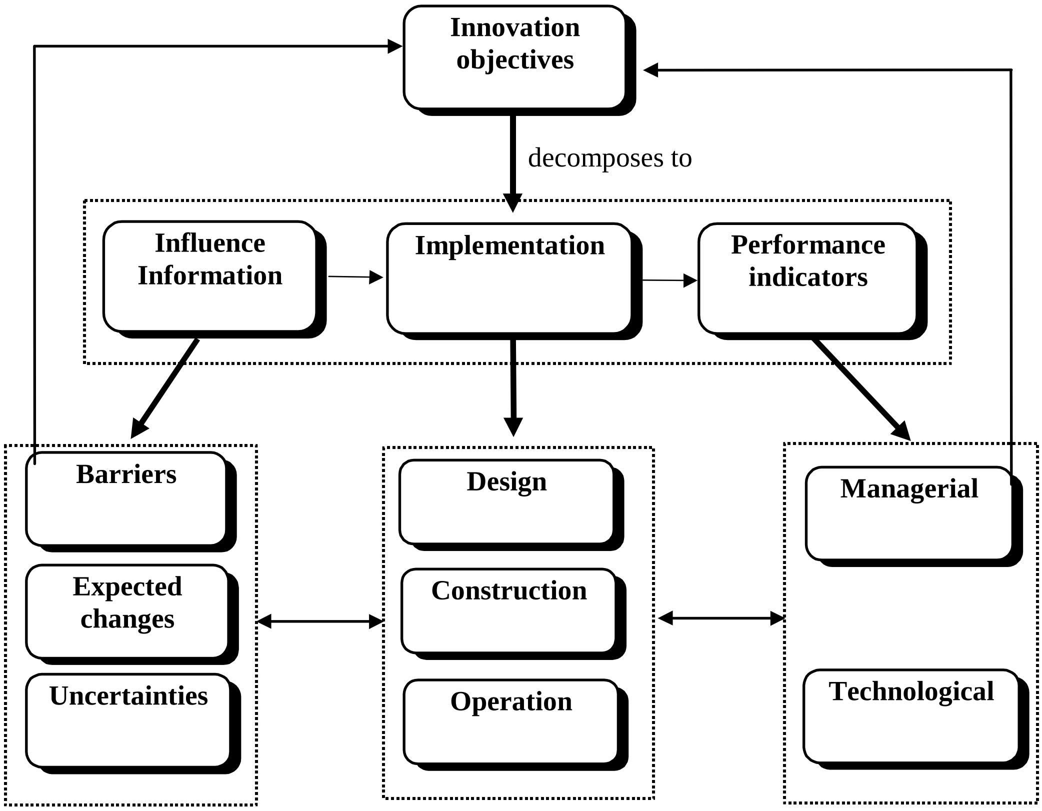

Figure 1: A generic conceptual model for innovation

society may have a significant effect on the construction industry if these are to be adopted. Support of strong research and development programs can achieve the strategic goal of innovation to gain more significant business market share. On the base of business objectives, innovation may not be established for a project as one unit, but it may be included in only some types of activities or even in one activity. As reported by De La Garza (1992), innovation objectives on the business base may include: higher turnover; higher profits; higher productivity; quality improvement; increased durability; and/or cost reduction.

Influence information

The proposed influence information refers to any aspect of knowledge involved in the decision to progress an innovation. As demonstrated in Figure 1, the influence information has been decomposed into barriers, changes and uncertainties. Barriers may result in increasing times or costs of innovation design or implementation. Managers should consider the probable barriers to innovation and estimate the effects on the implementation plan. The expected changes and deviations through the technological innovation process are often more than for non-innovative projects. Uncertainty sources during construction innovation can be related to any of the physical characteristics of the process; defective design and work; funding sources; and environmental risk and safety. The results of the first stage of this research have identified the information components as shown in Table 1.

Implementation

The proposed model suggests implementation as the plan that is designed to achieve the desired innovation. This phase of innovation contains the characteristics of a typical construction project and the iterative nature of innovation. Modifications are

Table 1: Influence information

Barriers	**Expected changes**
Building codes	The priority attached to the project
Reaction of other construction partners	Functional requirements due to the type of building
Labour relations issues	Funding and resources made available
Safety considerations	Owner's view
Economic and political conditions	Operational requirements
Capital intensiveness	Project aesthetics
Resistance to change	Market circumstances
Fragmented nature of the industry	Level of complexity of the project
Workforce skills	
Company size (capability of implementation)	
Governmental regulations	
Environmental and social constraints	

Uncertainties	
economic sources	**capability sources**
Yield (financial returns)	Damage to existing utility construction lines
Costs (financial estimates)	Safety risks
Time (how long it takes)	Productivity decline (learning curve)
Training requirements	Practicality of design and buildability
Availability of human resources	Technological function risk
Contractual claims	
Market changes	political and social sources
	Contractual and tendering methods
physical sources	Environmental risks
Substructure conditions	Government rules and regulatory bodies
Weather conditions	

often expected through this phase. The iterative nature may be applied to all phases or to some individual activities. The results of individual phases may be deterministic or stochastic. Stochastic results represent more accurately the uncertainty normally associated with innovative projects. Figure 1 suggests the implementation in its major sub-phases; design, construction and operation.

Performance indicators

Performance measurements should be incorporated to confirm the result of the implementation phase. The tangible (quantifiable) benefits of new technology can be accounted using traditional justification techniques. The justification process includes the potential savings in direct costs or time. The analysis of performance should not be limited to the tangible benefits. The increasing complexity of integrated technology makes measuring the intangible (qualitative) benefits of the new technology more difficult. The compound measuring of tangible and intangible benefit factors changes the basis of decision-making from numerical formulas to intuitive judgements. The list shown in Table 2 summarizes new technology indicators that may help in innovation assessment. It also demonstrates the technological benefits of innovation that have been concluded from the reviewed innovation cases in construction. Every innovation object has its own indicators that should be clearly and regularly measured.

Modelling the likelihood of particular implementation scenarios is complicated by uncertainty where the decision-maker lacks control over the consequences of one or

Table 2: Performance indicators

Managerial performance indicators	
TANGIBLE	**INTANGIBLE**
Profit	New function
Turnover	More expertise
Productivity	Efficiency
Quality (longer useful life, accuracy)	Effectiveness
Less material costs	Less errors
Less required jobs	Lower risk
Reduction of unit construction cost	Job satisfaction
Reduced workload	Service
Reduction of times	Work safety
Increased market share	Increase distinctive capabilities
Reduced training and supervision	Retention of a competitive advantage
	Reduced materials handling
	Synergy with other equipment
	Ability to respond quickly to future technology
	Level of environmental disruption
Technological performance indicators	
Structural serviceability	Speed of construction work
Practicability	Reduced floor space requirements
Fire safety	Increased utilisation of manpower and equipment
Compatibility	Reduced tooling, utilities and production control
Habitability	Reliability (concerning the probability of failure)
Maintainability	Flexibility
Durability	Improved product quality (reduced inspection)
Architectural function	Impact of new technology on other processes

more of the scenarios under consideration. A structured methodology based on subjective judgements, that puts the uncertainties into perspective and then takes them into account in the decision process, is one way to deal with these problems.

Cause-and-effect relationships among influence information to simulate innovation implementation are not always simple. It is necessary to analyse the influence diagram to draw conclusions about the relationship between the target and the variables. Conditions can be considered for these relationships by adding the probability of occurrence of the variables.

The expected changes in innovation implementation can be represented by:

- removing/changing existing links among variables;
- establishing new links within the process model;
- establishing new functional tasks; and
- repeating a certain process within the whole phase.

To develop implementation plans, the information links between processes in these plans can include heuristic rules and conditions. These links give alternatives or constraints for the succeeding step to fire using certain indicators depending on each approach elements. These indicators will incorporate the inherent uncertainty of expressing the efficiency of implemented innovations. Objective measures should be used as widely as possible to overcome bias in measurements of subjective measures.

This measurement of innovation performance may follow the iterative manner with the influence information and progress of the innovative project.

CONCLUSION

The long-term strategic benefits to be gained from construction innovation demonstrate the need for effective decision support tools that facilitate the innovation process and monitor its implementation. Although several models have been developed to help managers assess new technology, the process of innovation implementation has received less attention. The implementation phase includes several steps at which decisions should be analysed to react the changeable information. This paper presents a generic conceptual model that assesses the effectiveness of the innovation implementation phase. Benefits to be gained from improvements in operational efficiency are measured by cost and timesaving and increasing productivity. Competitive advantage (organizational effectiveness) results from the improved product quality and price, the additional services, and the improved technological image to the clients. These benefits need to be measured and quantified as indicators of achieving innovations and to provide an assessment of its implementation. This research aims to simulate this process which should simplify monitoring of the implementation and documentation of construction innovation problems that occur during the implementation phase activities.

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