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Computer-Aided Building Design Economics: An Open or Closed System?*

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INTRODUCTION

The use of economics in evaluating building designs has been proposed by a variety of authors over a number of years (see, for example, Stone, 1966 and Handler, 1970). The basic principles have not changed as reflected in more recent works on the subject of life cycle costs (Haviland, 1977; Marshall and Ruegg, 1980); and a set of generally accepted standards have been promulgated to insure the technical adequacy of life cycle cost procedures (ASTM E917–83). Nevertheless, life cycle cost principles have been slow in achieving acceptance as an integral part of the building design process.

A number of reasons for this reluctance have been proposed, including the variability of cost data, forecasting and uncertainty, interactions between the building and its users, and questions concerning the reliability and cost of life cycle cost analysis (Flanagan, 1984). While these arguments all have substantial merit, others (Kelly, 1984) suggest that significant acceptance will occur only when cost evaluation methods are presented to the designer in terms that the designer understands. This paper suggests that there are more fundamental issues involved in the use of economics within the design process. These issues revolve around the notion that building design economics is inextricably tied to a wide spectrum of design decisions involving assessments of both economic as well as non-economic performance issues. Most significant design decisions, it is argued, are made in this extremely rich and complex context. Designers intuitively make "trade-offs" and "cost–benefit" decisions that simultaneously consider many factors. The use of special purpose, stand-alone economic evaluation systems is inappropriate for this type of decision-making. This paper explores the implications of developing a computer-aided design system where economics is an integral, rather than separate, element in the design decision-making process.

DECISION-MAKING IN OPEN VERSUS CLOSED SYSTEMS

Because of the increased complexity of problems, rapidly changing societal needs, and the inability to solve many existing problems, a view is developing

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that many problems are not amenable to solution through traditional, reductionist models of research. This view suggests that many problems span across a variety of different disciplines, and that solutions may lie in the "process" as much or more than in the belief that there is an ultimate "solution".

One example of this change is illustrated by proposed methods for evaluating economic performance in computer integrated manufacturing. The manufacturing flexibility that emerges from this environment will allow for the production of "one-of-a-kind" products as easily and efficiently as current technologies provide for mass production. The implication of this capability has a far reaching impact on existing factory cost accounting and economic evaluation methods as well as management decision-making processes. Traditional economies of scale principles are being replaced by "economies of scope" (Goldhar and Jelinek, 1983). Historically, the type of product and production capacity of equipment were decisions that were more or less fixed. Day to day management of the factory enterprise was largely a function of maximising the use of these fixed assets. In this environment, operational results were measured by cost-per-unit, output-per-man-hour and other standard cost accounting practices. In the new automated factory environment these standard practices may provide little information that is of value to management decision-making. New methods are needed that address a wider range of issues, including: reducing set-up time, reducing uncertainty in the supply of materials, eliminating production problems, managing uncertainty in demand, and more appropriate measures of productivity and quality (Wingard, 1985).

Artificial Intelligence is another field that is exploring the problems inherent in making decisions within the context of open systems. Expert systems have traditionally relied on solving problems using logical reasoning within a set of predefined parameters. the general principles behind these systems usually involves developing evidence into a "logical proof" through the use of default assumptions, rules and/or probability theory and statistics. Artificial intelligence researchers are questioning the ability of these existing approaches to solve problems in which not all the facts or rules are known. In such a situation, logical reasoning cannot help provide a solution to the problem. To deal with the need to make decisions in the face of ambiguity, incomplete or conflicting information, and inconsistent beliefs, researchers are exploring the possibilities of using alternative approaches such as "due process reasoning" (Hewitt, 1985).

Design exhibits many of the characteristics of an open system (see Table 1). In many cases, the goals become clear only as the design progresses. Design is inherently interdisciplinary in nature, requiring the need for evaluation systems that support a range of structured as well as unstructured decision-making process.

Design problems have also been viewed as "wicked problems", in that they tend to be ill-defined, ill-structured, and ill-behaved. Two major characteristics of wicked problems have been identified as "openness" and "controversiality" (McCall, 1984). Because design tends to deal with unstructured problems, standard problem-solving strategies are not always helpful.

DESIGN REASONING AND ECONOMIC ANALYSIS

Several issues emerge as important when economic evaluation is considered as part of the design decision-making process.

(1) The economic performance of buildings is influenced by a wide variety of design decisions and design constraints. These include factors that range from the quantitative (*e.g.*, natural laws of physics) to factors that are inherently political or unstated (*e.g.*, codes or owner goals).

Table 1. Characteristics of open and closed systems

Open	Closed
Flexible	Fixed
Dynamic/changing	Static/unchanging
Many links with other subsystems	Few links with other subsystems
Decentralised	Centralised
Variable goals	Fixed goals
Ambiguous	Unambiguous
Unstable	Stable
Unstructured decision process	Structured decision process

(2) Economic performance is influenced by the complex interaction of these factors with each other. These interactions are frequently difficult to understand, and may be confounded by such factors as time lags and differing perceptions on the part of various participants in the design process.
(3) The nature of economic predictive models is such that they are full of inherent ambiguity and risk. No one can predict the future with certainty.
(4) Cost performance, by itself, can be a rather meaningless indicator of the relative worth of a building design. Designers as well as most building owners are interested in the ratio of cost and benefits rather than just costs.

Because the design problem is inherently open-ended and interdisciplinary and because economic performance is inextricably linked to these design decisions, building economics evaluation systems may be more appropriately operationalised within the context of an open system.

IMPLICATIONS FOR COMPUTER-AIDED DESIGN RESEARCH IN ECONOMICS

If building design economics is considered an open system, then existing computer based methods for evaluating the comprehensive performance of buildings are inadequate. They are inadequate because they do not provide the type of support that is necessary for making design decisions. Consider the preliminary design sketches in Fig. 1. These drawings are performed in an effort to support the design decision process. The kinds of support that are needed may be anticipated by analysing these drawings. In this example, there is an apparent need for a visual representation of the evolving design (plans and elevations), a need to associate scale and dimensions, and a need to test the design to insure that a target total square foot requirement has not been exceeded (a crude form of cost evaluation). These sketches, however, only partly reveal the actual complexity of information integration that is actually occurring. For example, the drawings are a backdrop for overlaying the multiple systems that are simultaneously being considered with the layout of the spaces, including: structural, plumbing, lighting, duct runs, and others. Each of these other systems are visualised by the designer in the context of the sketches and in the process of sketching.

This design process, although rich in its ability to support design thinking about integrating many different types of systems, is limited in that it cannot support extensive analysis of the evolving design. For example, it is a relatively poor method for accurately evaluating energy or economic performance.

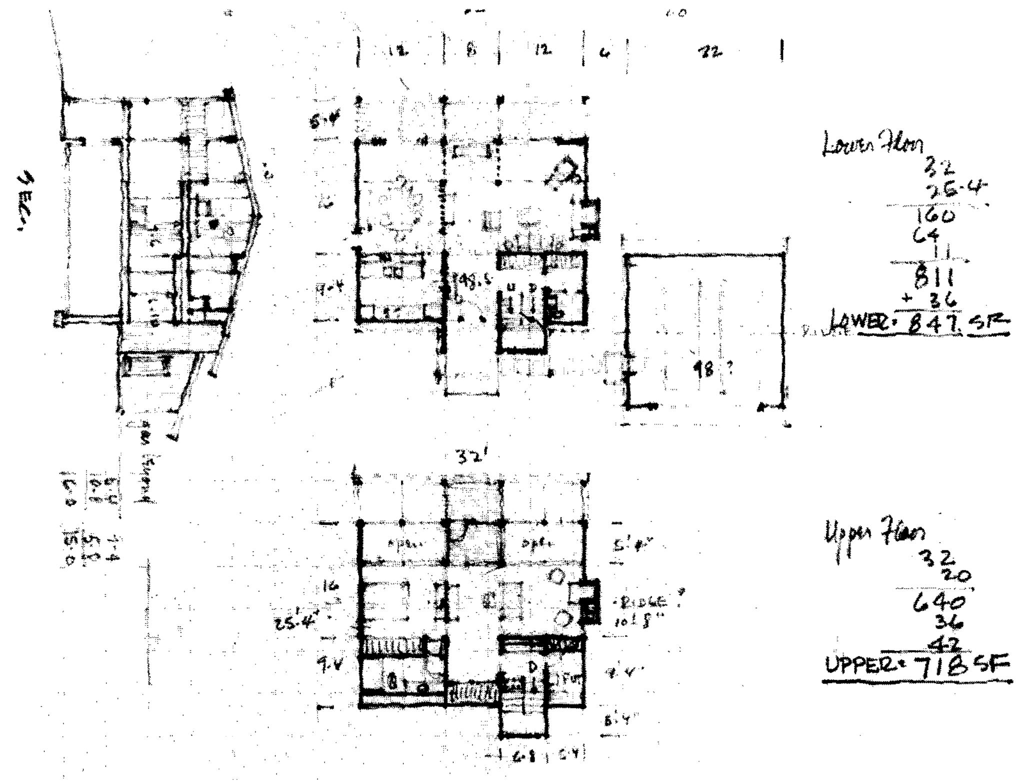

Fig. 1. Design drawings by R.C. Metcalf.

MULTIPLE REPRESENTATIONS FOR DESIGN

The question to be addressed is how to conceptualise a computer-aided design environment that provides the capability for visualising an evolving design and allows for the simultaneous, rigorous evaluation of that design from multiple perspectives. One approach to this problem is to provide the ability for the designer to select from a wide variety of possible design representations. The ability "to switch back and forth between several forms of representations — words, symbols, pictures — and to look at a problem from a variety of different perspectives as we seek a solution" (Lenat, 1984, p. 211) is an important characteristic of creative problem-solving. In order to support the design process, software systems should have this ability to support multiple representations and be able to facilitate the transition from one representation to another.

Figure 2 is a diagram of research that is addressing this issue of multiple representations. The research has used the spreadsheet, or worksheet metaphor as a context for this investigation. Figure 2 illustrates three possible views of the worksheet. Sheet 1 presents the "values" or results of the evaluation. Sheet 2 presents the "value rules" that were used in the calculation of the values. Sheet 3 presents the geometry, or model of the design, that the value rules operate on to produce the values. In this specific example, the area that was used in the calculation of NET square footage is shaded. The actual implementation of this worksheet is presented in Fig. 3. One of the advantages of the multiple representation approach is the ability to provide an additional method for validating value rules. For example, without the drawing it would be more

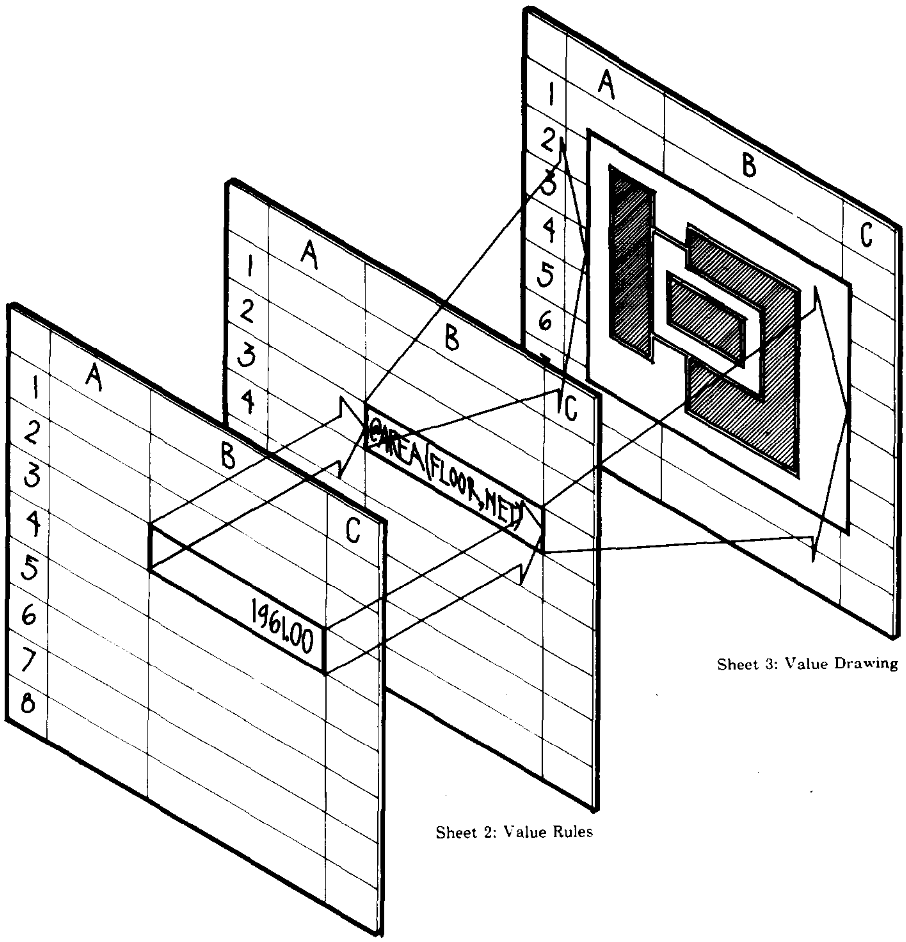

Fig. 2. Illustration of multiple representations for worksheets.

difficult to verify which spaces were used in the calculation of net area. Future research needs to be conducted on the development of alternative metaphors that encourage the integration of a richer mix of design representations.

INFORMATION MODELS

A prerequisite for the use of multiple representation models is the development of database models that provide for dynamic adjustments to the design of the database. At least two situations may require this type of dynamic adjustment. First, as the design of a building evolves through the design process (planning, programming (brief writing), space layout, design development) the database required to support alternative representations undergoes fundamental changes. For example, the shift from space layout to design development involves a change from emphasising the size and arrangement of spaces to the design and spatial integrity of constructed elements. Another example is the shift of information organisation that occurs between the design development phase and construction of buildings.

A second situation may occur when a variety of different design disciplines are working on one building design. For example, the analysis of plumbing or electrical riser diagrams may be based on a fairly abstract line or network

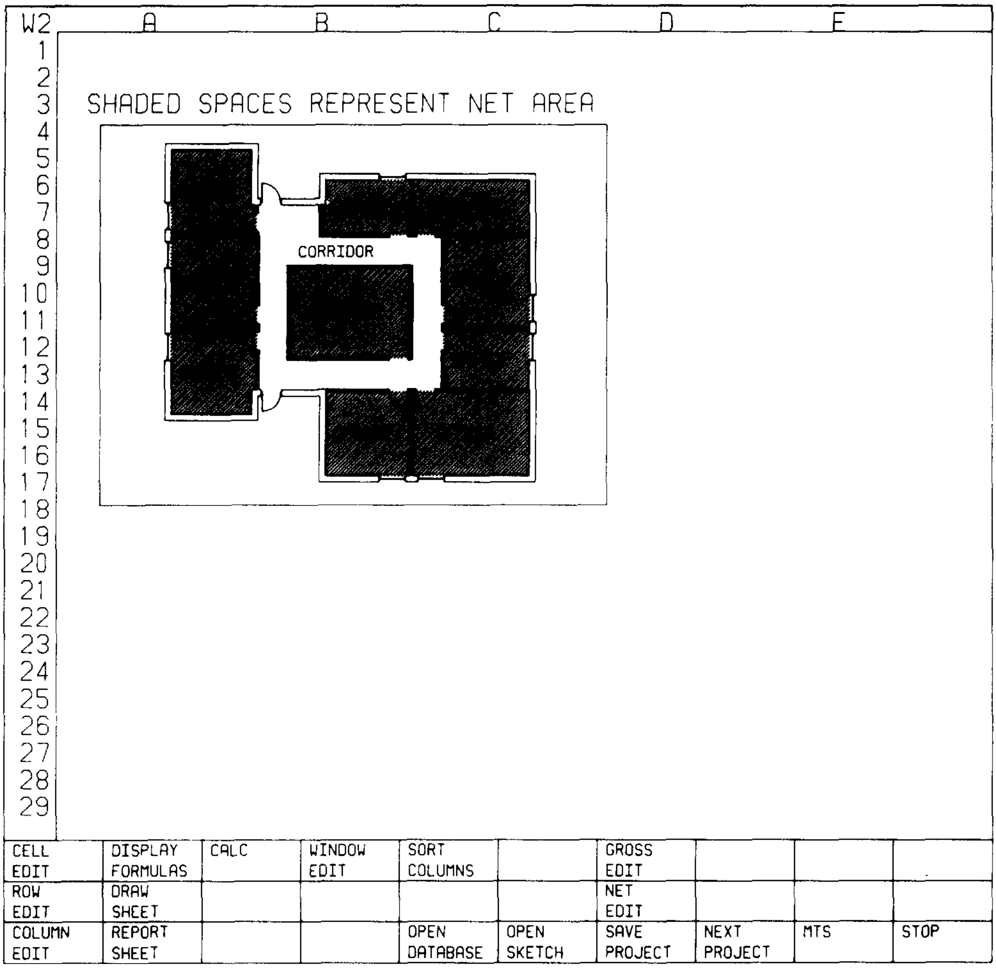

Fig. 3. Implementation of multiple representations.

representation, while the model used by interior designers may focus on a departmental or room by room system of organisation. Future research in computer-aided design economics needs to assess the impact of the information needs of various design stages on database management. One possible direction is to augment storage, retrieval and updating mechanisms with semantic knowledge. Recently, Stonebreaker (1984) suggested that a rules system and abstract data types be included at the column or domain level of relational systems. Also in the context of dynamic database management, Borkin (1985) has presented some approaches that deal with the concept of trigger domains and their impact on other relations.

COMPUTATIONAL MODELS

Information models alone are insufficient for economic analysis, since they deal primarily with storage and retrieval of data and not with the means to govern the analysis of data. Computational tools are required so that information retrieved from the database may be combined with appropriate algorithmic processes to test the performance of a proposed building design alternative. These tools correspond to the "test" in the generate and test cycle that is typical of many design processes (Simon, 1981). However, the design of these tools is critical. Within the context of an open system, it may not be possible to always determine the exact nature of some of these evaluation techniques prior to their use. In addition, the design of the evaluation mechanism must be capable of adapting to a wide variety of analysis needs throughout the design process.

One approach to addressing these issues through the use of the worksheet metaphor is illustrated in Fig. 4. Figure 4a presents an example of a simple cost model where the area of internal partitions is multiplied by the unit cost per square foot of partition to arrive at a total cost. Figure 4b is the "value rule" representation of the worksheet which shows the formulas that were used in the computations and the interior partition drawing of the geometric model that was used in arriving at the final calculation. The flexibility of this modelling approach appears to have some of the characteristics required for the application of a wide variety of computational models to integrated design evaluation systems. Further research needs to be conducted to facilitate the logical selection of computational models based on the context required for design evaluation.

(a)

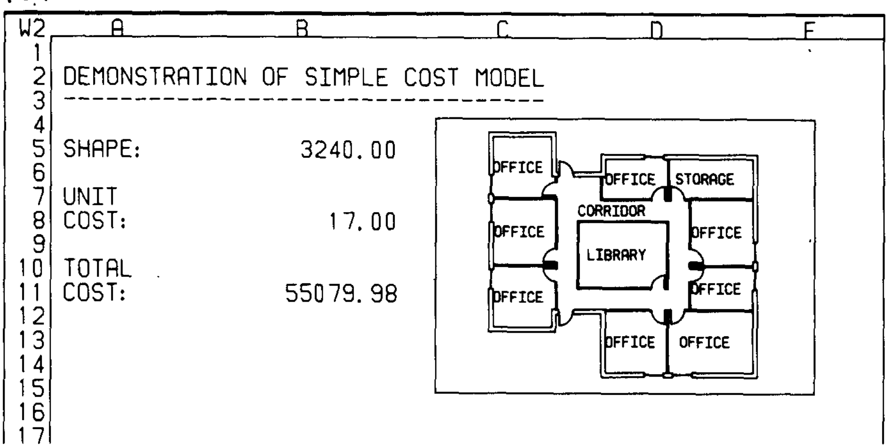

Fig. 4a. Simple cost model: values.

(b)

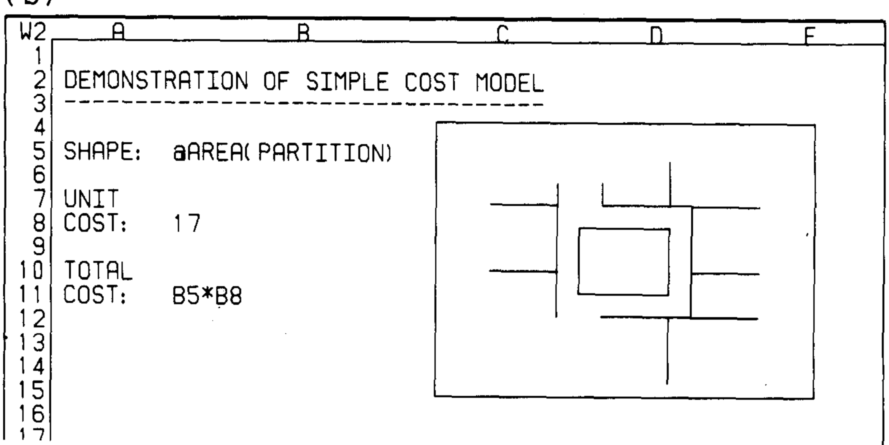

Fig. 4b. Simple cost model: value rules.

CONCLUSIONS

This paper has argued that building design economics has not been particularly successful because it has been viewed as a closed system that deals primarily with problems that are specific to the domain of economic evaluation. Design problems, on the other hand, are characterised by interdisciplinary, ambiguous and unstructured decision processes. The integration of economic principles and building design will not be successful until economic assessment mechanisms become more directed towards the open-ended nature of the design process. This paper has suggested several researchable issues that are directed towards resolving these issues.

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