VALUE ENGINEERING AND OPTIMAL BUILDING PROJECTS

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ABSTRACT: The goal of any engineering design is to obtain an optimal solution to the design problem. This paper examines how value engineering contributes to the process of obtaining an optimal solution to the design problem for a building project. The factors that determine a building project and its costs are listed and these factors fall into two groups; one group relates to specific engineering systems, while the other group is general in character and relates to the whole building. Value engineering is effective because its procedures give opportunities for raising design issues associated with the latter group of factors as well as for providing for peer-review of the design. A summary of other methods of optimal design—such as design for manufacture and assembly (DFMA), concurrent engineering, and total quality management—is given, and these methods are compared with value engineering. Cost minimization in building construction is discussed with examples from the writer's experience on building projects in West Africa and the Middle East.

INTRODUCTION

One definition of engineering that has come to this writer's attention is that,

> "Engineering is the conceptualization, design, construction, and administration of projects and products. Whatever the field or application, the engineer solves problems with imagination, creativity and synthesis of various sources of knowledge."

Value engineering is one tool available to the engineer, and its application on projects and products guides the engineer's imagination, creativity, and synthesis of knowledge such that whole-life value is achieved for the project or product. Essentially, the project or product is viewed from its purposes and functions through to its conception, actualization or manufacture, and usage—and simultaneously in a reverse order from its usage back to its purposes and functions. Although value engineering has its origin in the manufacturing industry, its methodology has been well developed for use in the construction industry (Dell'Isola 1988). The realization of whole-life value for a building project involves finding optimum combinations of initial project costs, maintenance costs, and costs associated with the time for completion of the project.

The procurement system for a building involves the interaction of the building owner, the building designers, and the builder. In an ideal situation, this interaction should result in a building that meets the owner's needs and expectations and that is cost-effective to construct, use, and maintain. The building owner, the building designers, and the builder will exchange information and will be responsible either individually or collectively for making various choices and decisions in respect to the building. This paper aims at encouraging the use of value engineering so that the ideal situation is arrived at more often than not.

OPTIMAL BUILDING PROJECT

The optimal building project has as the measure of performance the initial project costs, the life-cycle costs, and the time for completion of the project.

The factors that determine a building project and its costs are as follows:

1. The purposes and functions for which the building is intended
2. A clear concept of the owner's total needs
3. The aesthetic appeal of the building to the public and the public's perception of value in the building
4. The architectural systems and finishes specified for the building, and the need for these systems and finishes to perform under operational conditions
5. The structural form and materials—the need to maintain the building in stable equilibrium under all expected loading conditions
6. The heating, ventilating, air-conditioning, and public health systems specified for the building and the need to provide a comfortable environment to building users under operational conditions
7. The lighting, electrical power, and telecommunications systems specified for the building and the need to provide reliable and adequate services under operational conditions
8. Fire detection and fire-fighting systems specified for the building, the need for these systems to function under all operational conditions, and the need to provide for evacuation of the building in an emergency
9. The method of construction, the ease of construction, and the time for completion of construction
10. The ease of maintenance, the replacement cycle of components, and maintenance requirements
11. The need for the investment in the building to show a profit.

The initial process in defining a building project is largely conceptual, and therefore relies on a broad knowledge base of the design team in presenting viable options. The final process involves engineering calculations, which give a precise form to the project. As an example, consider the structural system in a masonry/concrete building on three levels. In the final process, the first solution-step is the determination of the structural form of the building from the spaces defined in the architectural drawings. Next, structural calculations lead to designs for determination of member sizes and steel reinforcement in the reinforced concrete structure. The objective of these structural designs is cost minimization through minimizing member sizes and steel reinforcement in the reinforced concrete structure.

The use of computers in carrying out the structural calculations referred to above leads to a situation in which a large number of alternative options can be considered for the structural form of the building. However, optimization studies for elastic design of structures have shown that approximate formulation of the design problem is necessary for its solution (Reinschmidt 1971). Simplification removes insignificant fac-

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tors and renders the problem more manageable; it also leads to a reduction in the computational effort required for obtaining solutions. Making approximations in an optimization procedure does not invalidate the procedure, as the alternative of a search through every possible solution may not yield any significant differences where the objective is cost minimization in a building project.

The characterization of the optimal building project has as its objective the minimization of the combination of initial project costs, life-cycle costs, and costs associated with the time for completion of the project such that all the factors that determine the building project as enumerated above are considered and conflicting needs arising from the factors are satisfied. The optimization of any building project can readily be seen to be complex. However, design is an iterative process, and there are techniques or methods of optimal design which assist the identification of significant elements of the design in the search for an overall optimum. Some of the methods of optimal design, including value engineering, are discussed below.

VALUE ENGINEERING

Value engineering can be defined as the process of relating the functions, the quality, and the costs of the project in the determination of optimum solutions for the project (Dell'Isola 1988). The application of value engineering to a project usually starts with a specific solution to the project that can be called the initial solution. Value engineering also identifies a level of quality for the project, and this initial solution is examined against a background of this level of quality. The examination of the initial solution through the application of the procedures of value engineering leads to a final solution, in which the costs of the initial solution are optimized.

The procedures of value engineering are applied in phases by a multidisciplinary study team. The first phase is the information phase, in which all information relevant to the project is obtained, a profile of costs for the project is determined, functions are analyzed, functional relationships are represented in a FAST diagram, and costs of various functions on the FAST diagram are identified (Dell'Isola 1988).

Next, the study team generates ideas that allocate resources on the basis of the significance of the functions and which optimize the costs of the various functions. The ideas are evaluated, and the best ideas are chosen and developed into the final solution.

The procedures of value engineering lead to a solution that emphasizes the role of the functions of the project, seeks to achieve whole-life value for the project, and relies on the best judgment of the study team in making final design choices.

FOUR METHODS FOR OPTIMAL DESIGN

The goal of any engineering design is to obtain an optimal solution to the design problem. Procedures for obtaining optimal solutions include the following: design for manufacture and assembly, concurrent engineering, total quality management, and value engineering.

Design for manufacture and assembly (DFMA) can be described as a design-review method that identifies the optimal part design, materials choice, assembly, and fabrication operations to produce an efficient and cost-effective product (Constance 1992; Ashley 1995). DFMA is applied by a multidisciplinary team that includes design engineers, manufacturing engineers, shop floor mechanics, suppliers' representatives, and specialists in production support, maintainability, and reliability. The DFMA software and database system allow its users to (1) produce detailed designs of each of a product's individual parts based on requirements of ease of assembly and structural efficiency, (2) to select the most feasible manufacturing process at the concept stage, and (3) to predict the assembly and manufacturing costs.

Concurrent engineering can be described as a seamless systematic integration of product design, engineering, and manufacturing as well as postmanufacturing product life-cycle management (Ashley 1992). Product design engineers, manufacturing engineers, production engineers, and marketing personnel interact and share the same project information over the same time frame in the process of obtaining optimal solutions to the design, manufacturing, production, and marketing requirements of the product. As an example, the Japanese ''tiger team'' approach involves gathering a multidisciplinary team together at the start of a project to work out a solution that meets the concerns of each individual team member and each engineering discipline. The procedures of concurrent engineering contrast with the procedures of sequential engineering, in which a completed product design is passed first from the product design engineers to the manufacturing engineers, next to the production engineers, and finally to the marketing personnel.

Total quality management involves the implementation of quality systems for all of an organization's activities. The organization's operating procedures are documented and, if necessary, improved upon. Subsequently, audits and reviews are carried out to ensure that the procedures are adhered to and that the quality systems are effective. The goal is a quality product that meets its intended functions with minimum variability in key performance characteristics between any two copies of the product.

Value engineering, design for manufacture and assembly, concurrent engineering, and total quality management all have their origins in the manufacturing industry. Whereas DFMA is specific to manufacturing, value engineering, concurrent engineering, and total quality management can be readily applied to building projects. It should be noted that DFMA can be applied to building projects using modular construction.

These methods for optimal design have in common the use of a structured approach, the use of multidisciplinary teams, and the assumption of good design teams made up of experienced personnel. The methods take advantage of the computational capability made available by computers, enabling several alternatives to be considered before a final choice is made. The use of value engineering implies that one team does the initial design while another team applies value engineering to the initial design, the result of which is a final solution incorporating improvements to the initial design. Value engineering thus emphasizes peer-review that forms part of good design management when using concurrent engineering or total quality management.

There could be the tendency to dismiss value engineering as a subjective method of optimal design. However, it is important that the usual starting point for the solution procedure is a feasible design of the project; also, that the objective is a cost-effective design and the solution procedure identifies significant elements to which the design team applies its broad knowledge base, resulting in improvements to the design.

OBSERVATIONS ON COST-EFFECTIVE BUILDING PROJECTS

Cost minimization in building construction can be achieved, in this writer's experience, by using appropriate designs, materials, and processes. One design issue that comes up frequently is the clear definition of the owner's space requirements. The owner will usually indicate room spaces required without specifying the areas of these rooms. Studies have shown that significant savings in building costs are made when room sizes are specified in accordance with their functions and when the rooms are arranged to minimize space required for circulation purposes.

Foundation construction in loosely compacted coastal sands in West Africa and in expansive soils in the Middle East is a design issue that can be resolved through appropriate designs. It has been observed that for a residential building on two or three levels, a reinforced concrete slab below ground surface is usually specified for the foundations in the coastal sands in West Africa. Ground beams and columns complete the substructure to the level of the grade slab above the ground surface, and the whole substructure construction is referred to as a raft foundation. An alternative and more cost-effective solution is to use trapezoidal ground beams at the ground surface, with the grade slab acting as a diaphragm linking the ground beams. This form of foundation construction will be found to also be cost-effective in expansive soils in the Middle East as an alternative to recommendations for soil replacement or for the adoption of a soil-wetting procedure directed at producing an ‘‘equilibrium moisture content’’ in the soil (Dhowian and Touma 1992).

Concrete masonry units (CMUs) are used for wall construction in buildings in the Middle East. These CMUs do not usually have their drying shrinkage within the permissible limits for drying shrinkage of concrete. In order to avoid the formation of cracks in walls, the construction incorporates a layer of galvanized metal lath every third course of the wall. The typical CMUs are made with a vibrating plate at the bottom of the unit and a manual press at the top. It has been found, however, that with a hydraulic press at the top, the units produced are denser and better meet the permissible limits for drying shrinkage of concrete.

The structural behavior of CMUs provides an example in using appropriate designs. In the course of a housing project, load tests were carried out on two sets of CMUs made from the same materials, with the same overall dimensions and the same weight but different designs. One set of CMUs had two rectangular cells making up its cross section, while the other set had three rectangular cells. In effect, the two-cell CMU and the three-cell CMU had equal cross-sectional areas and equal depths. The CMUs were tested to failure by application of loads on their cross sections. It was observed that the crushing strength of the three-cell CMU was about 50% of the crushing strength of the two-cell CMU. The failure zone in the two-cell CMU was at joints of vertical panels making up the CMU. However, the failure zone in the three-cell CMU was in the middle of the vertical panels making up the CMU. The failure mode and load suggested a buckling-type failure in the three-cell CMU. Although the two-cell CMU and the three-cell CMU were produced at the same cost, the former clearly provided better value.

Life-cycle assessment has become significant for concrete structures in aggressive environments in the Middle East. Deterioration of concrete structures has been known to occur within a few years of construction (Simm and Fookes 1989). In particular, chloride-related reinforcement corrosion increases reinforcement size, resulting in cracking and spalling of the concrete. This has given rise to a situation in which cathodic protection is being applied to new construction in the Arabian Gulf region (Schutt 1992). The alternative to providing cathodic protection is to take stringent measures during the construction of the structure. Given the high humidity, salts in the atmosphere can condense during nighttime temperature drops, leading to rusting of the steel reinforcement. Thus it will be necessary to clean all reinforcement before concrete is placed. The use of low-heat cement, in addition to keeping the temperature of fresh concrete below 32°C, inhibits plastic cracking, thus limiting moisture entering the completed structure from the atmosphere. Concrete in contact with the ground is waterproofed using a bituminous membrane.

Life-cycle considerations are also significant in the choice of heating, air-conditioning, and ventilation systems for buildings. Energy-efficient buildings will usually require that their heat losses/gains across their external envelope be minimized. In Saudi Arabia, residential construction usually consists of uninsulated external walls and insulated flat roofs. However, given rising energy demand and the substantial capital costs of meeting this demand, building regulations now stipulate that external wall construction should be a cavity wall with insulation in the wall gap.

The factors that determine a building project and its costs can be separated into two groups, one consisting of factors relating to specific engineering systems, the other to factors that are general in character and related to the whole building. Most of the examples given above are for specific engineering systems. For some of the engineering systems, such as the structural systems, computer-based optimization routines are available for obtaining solutions to the design problem (Lane and Harriman 1975; Puttre 1993).

Value engineering is effective because its procedures give opportunities for raising design issues, associated with the factors, that are general in character and related to the whole building. The first example above touches on two factors whose consideration results in significant savings in value engineering studies. These factors are the purposes and functions for which the building is intended and a clear concept of the owner’s total needs.

Value engineering studies have aided the realization of projects through the scheduling and postponement of expenditure. The studies identified elements that were critical and sufficient for getting a project started and from which adequate economic returns could be made. The possibility of getting returns on initial investment before further investment is made has led to a situation in which capital funds were readily available for some investment projects. In the case of one project for a charitable institution, the limited funds available were applied to the construction of some portions of the project. The realization of these portions of the project encouraged donors to make contributions toward the construction of other portions of the project.

CONCLUSIONS

A building project and its costs are determined by a number of factors, including its functions and purposes, its aesthetic appeal, its profitability, the owner’s needs, the performance specifications of its architectural and engineering systems, the construction method and completion time, and its maintenance.

Value engineering can be defined as the process of relating the functions, the quality, and the costs of the project in the determination of optimum solutions for the project. In common with other methods of optimal design such as design for manufacture and assembly (DFMA), concurrent engineering, and total quality management, value engineering uses a multidisciplinary team.

In applying value engineering to a building project, the multidisciplinary team obtains a solution that emphasizes the functions of the project and the best judgment of the team in making final choices, and which results in a cost-effective design for the project.

The factors that determine a building project and its costs can be separated into two groups: one consisting of factors related to specific engineering systems and the other of factors that are general in character and relate to the whole building. Value engineering is effective because its procedures give opportunities for raising design issues associated with the latter group of factors, as well as providing for peer-review of the designs.

REFERENCES

Ashley, S. (1992). ‘‘DARPA initiative in concurrent engineering.’’ *Mech. Engrg.*, 114(4), 54–57.

Ashley, S. (1995). ‘‘Cutting costs and time with DFMA.’’ *Mech. Engrg.*, 117(3), 74–77.

Constance, J. (1992). ‘‘DFMA: Learning to design for manufacture and assembly.’’ *Mech. Engrg.*, 114(5), 70–74.

Dell’Isola, A. J. (1988). *Value engineering in the construction industry*, Smith Hinchman & Grylls, Washington, D.C.

Dhowian, A. W., and Touma, F. T. (1992). ‘‘Water sensitive soils in Saudi Arabia.’’ *Proc., 3rd Saudi Engrg. Conf.*, King Saud University, Riyadh, Saudi Arabia, 110–115.

Lane, V. P., and Harriman, H. (1975). ‘‘Minimum cost design using a preplanned nodal search method.’’ *Proc. Instn. Civ. Engrs.*, London, Part 2, 59(June), 237–253.

Puttre, M. (1993). ‘‘Putting optimization routines in the loop.’’ *Mech. Engrg.*, 115(7), 76–80.

Reinschmidt, K. F. (1971). ‘‘Discrete structural optimization.’’ *J. Struct. Div.*, ASCE, 97(1), 133–156.

Schutt, W. R. (1992). ‘‘Cathodic protection of new high-rise buildings in Abu Dhabi.’’ *Concrete Int.*, May, 45–46.

Simm, J. D., and Fookes, P. G. (1989). ‘‘Improving reinforced concrete durability in the Middle East during the period 1960–1985: An analytical review.’’ *Proc Instn. Civ. Engrs.*, London, Part 1, 86(April), 333–358.