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Applications of design intent in value engineering

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ABSTRACT

The increasing complexity of building facilities highlights the need for improved communication among the numerous Architecture-Engineering-Construction (AEC) participants involved in a single project. The AEC industry implements value engineering programs not only to improve the life cycle cost effectiveness of these projects, but also to improve the communication of design intent among the project participants. This paper briefly describes the design intent and value engineering concepts from the point of view of the AEC industry. Emerging computer technologies such as computer-aided design and artificial intelligence are necessary in the implementation of the coupling of these two concepts. This coupling improves the efficiency of the value engineering process. The paper also presents a prototype computer-aided value engineering (CAVE) system currently under development. The implementation of a CAVE system embeds the value engineering process in the design process and forms the foundation for a computer-integrated facility life cycle concept.

INTRODUCTION

Building projects are getting increasingly more complex. The Architecture-Engineering-Construction industry, however, is still using paper drawings and specifications to convey project information among the various parties involved in the project. Clearly, this communication method is no longer sufficient for the complexity of current building projects, as evidenced by the Kansas City Hyatt Regency Walkway Collapse. 114 people died and 185 injured when two suspended walkways connecting the main hotel and the convention center collapsed. One of the causes of the collapse was that the change proposal by the contractor regarding a constructability issue of the hanger rods did not conform to the intent implied by the designers in the design drawings, Marshall et al. [15].

The construction cost of actual facilities increases in direct relation to the complexity of the project. As project complexity increases, there are many different ways to go about constructing the facility. Project designers are typically just given enough time to consider a few alternatives, if at all. The US government recognizes these facts by encouraging contractors to bring their wealth of field experience to bear on federal projects. The government encourages the contractor to submit construction work alternatives that will result in cost savings but not at the expense of quality or performance. The government and the contractor share the savings associated with the proposed alternatives. These contract clauses, called Value Engineering Clauses, are required in federal contracts expected to be worth at least $100,000. These clauses are optional in federal projects less than $100,000, Federal Acquisition Regulations Title 48 Clauses 48.201, 48.202, 52.248 [6].

The US Army Corps of Engineers also considers these complexity issues. They, however, approach it from a different viewpoint. The Corps is responsible for engineering projects totalling billions of dollars annually. As such, they implemented an in-house value engineering (VE) program. This in-house program conducts VE studies on various projects while they are still in the design stage. The Office of the Chief of Engineers' Value Engineering Study Team (OVEST) conducts these VE studies. In short, VE is practiced in both the design and construction phases of the facility life-cycle.

This paper describes the coupling of design intent and VE concepts. The purpose of this paper is to develop a framework for a computer-aided value engineering system. This concept is not entirely new as several others have already identified artificial intelligence as being able to support the VE process, Al-Yousefi [1], Gibbs [9], Shen and Brandon [16]. This paper also presents software development efforts done to date on a prototype system.

DESIGN INTENT

Design is the process of transforming a need requirement into a physical representation model capable of satisfying such need. Design intent can be broadly described as a collection of all the data, knowledge, and reasoning leading to the creation of a design. Externalization of design intent can also be thought of as storing the design process together with the design product for retrieval at a later time, Coyne et al. [2], De La Garza and Oralkan [3], Ganeshan et al. [7], Howard [11], Kim [13].

Design intent can be divided into two types: owner's intent and designer's intent. Owner's intent comprise the set of needs and wants the facility must satisfy. On a project level, some specific examples of owner's intent are building type (e.g. college, hospital), building capacity (e.g. 10,000 enrollees, 5,000 beds), and special owner requirements (e.g. aesthetics consistent with being an

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institution of higher learning, 100% operable after a major earthquake). On a lower level, space type (e.g. conference room), space capacity (e.g. thirty people), and special owner requirements (e.g. room must be conducive to Board of Directors meetings) are some specific examples of owner's intent.

Designer's intent constitute the transformation of owner's intent into descriptions of physical objects. Given a set of owner's intents, designers transform these into a set of functional requirements. The functional requirements are, in turn, further transformed into descriptions of physical objects. These physical objects have the performance attributes and physical properties necessary to satisfy the functional requirements. Considering the conference room as an example, designers transform the board meeting requirement (owner's intent) to visual and acoustical functions (functional requirements). These functions are further transformed into ambiance and filter sound performances (performance attributes) and further into wall finish esteem value and wall sound transmission coefficients (physical properties).

Most of the design intent or the reasoning behind these transformations are lost in the current method of exchanging project information. Paper design drawings and specifications only show how the product is supposed to look like. The reasonings behind the physical representation of the product remains trapped in the minds of the owners and designers. In response to this problem, some research has been done to capture intent for use in stages downstream to design such as construction and operation. The Skull Object Space model, De La Garza and Oralkan [3] and the Augmenting Design Decision model, Garcia and Howard [8] are two examples of computer-based models capturing design intent.

VALUE ENGINEERING

One of the best descriptions of VE is that given by Hendrickson and Au [10 p.70]: "Value engineering is the organized approach in identifying unnecessary costs in design and construction and in soliciting or proposing alternate design or construction technology to reduce costs without sacrificing quality or performance requirements."

The basic building block of the VE study process is the functional analysis task. The building functions are classified into basic or secondary functions, Dell'Isola [4], Zimmerman and Hart [17]. Basic functions are similar to owner needs while secondary functions are similar to owner wants. Functional analysis not only points out those functions that are not essential, but it also allows the VE team to think about design alternatives that are based on its function and not based on the design itself. Taking the conference room as an example once again, if functions are not considered, wall type X costing 10 units might be replaced by wall type Y costing 5 units. However, wall type X was chosen over wall type Y by the designer because of its performance level of 5 for function Z as compared to wall type Y's performance level of 1 for the same Z function. Clearly, VE without functional analysis is merely cost cutting and is not really VE.

Owners, designers, builders, and other specialists involved in the life cycle of the project compose the VE team. This team analyzes the project objectives, identifies and solicits alternatives to high cost items. They accomplish the VE study through the use of a formal job plan. The various phases in this job plan are as follows: (1) Information, (2) Speculation, (3) Analysis, (4) Development, (5) Recommendation, and (6) Post-Occupancy Evaluation, Dell'Isola [4], Kirk [14], Zimmerman and Hart [17].

Studies of available literature, Dell'Isola [4], Kirk [14], Zimmerman and Hart [17] as well as knowledge elicitation studies conducted by the writers with OVEST, form the basis for the following descriptions on the various VE phases. OVEST allowed the writers to participate in two value engineering studies they recently conducted.

The Information phase involves retrieving information on the project scope and requirements as determined by the owner. The VE study team also tries to retrieve as much information as it can on the project design development. The current method of exchanging information through paper drawings necessitates a lengthy description of the design development by the design team. The VE team breaks the project into its functional requirements and presents cost breakdown structures for the project. These pieces of information guide the VE team in the Speculation phase.

The VE team suggests function-based alternatives to probable high cost design areas in the Speculation phase. In the course of suggesting alternatives, additional information may be required, as such, the Information phase continues on through this phase, albeit on a minor scale. The VE job plan requires that no analysis be done in this phase but rather all analysis shall be deferred until the Analysis phase.

The Analysis phase begins after the VE team runs out of alternative suggestions. The VE team discuss the relative merits and demerits of all the proposed alternatives one by one. Alternatives that both conform to the project functional requirements and seem more promising in terms of quality enhancement and/or life-cycle cost savings are slated for further development.

The various parties involved in the VE study complete the development of the promising alternatives. After the completion of this development, the VE team evaluates the quality enhancement and/or life-cycle cost savings of the proposed alternatives as compared to the original design. Alternatives that have significant quality enhancement and/or life-cycle cost savings are recommended to the owners for possible implementation. After the project has been constructed and is in operation, implemented alternatives are re-evaluated with respect to their actual performance. This is to find out if indeed the VE proposal resulted in actual quality enhancement and/or life-cycle costs savings.

PROSPECTUS FOR APPLYING DESIGN INTENT TO VALUE ENGINEERING

Access to externalized design intent information will give value engineers the ability to understand the design development before the start of the Information phase. The value engineers will therefore enter the Information phase with a clearer understanding of the project's design as compared to when they did not have access to design intent. The value engineers will then be able to immediately ask the designers more specific questions regarding the design, as compared to the present method where the designers explain lengthily their design before the value engineers can ask questions. Thus, design intent will bring efficiency to the Information phase.

Despite attempts to externalize intent at the design stage, there will always be intent that remains implicit. This implicit intent will be the focus of the questions of the value engineers. Intent externalization does not end at the design phase. Rather it continues on through the VE Information phase and through the other VE phases as will be shown later.

The availability of design intent information makes the VE team more knowledgeable about the project requirements and design development. Therefore, in the Speculation phase, the VE team can suggest alternatives that comply with user requirements. The VE team can also avoid suggesting alternatives that the owners or designers already considered as unacceptable.

The VE team can use design intent as a check on the feasibility of the speculated alternatives in the Analysis phase. Intent externalization also continues in this phase. The alternatives slated for development have themselves some rationale behind them. As such, this rationale should be captured for use in latter stages (VE Development phase, construction stage, maintenance stage).

The Development phase involves the revision of the design drawings to incorporate the VE alternatives. Access to the VE intent helps the designers avoid creating unsatisfactory redesigns because of misinterpretation of the alternatives. The VE alternative is analogous to the user requirements in the design stage. The designers transform this VE alternative proposal into a VE alternative design. Additional intent is generated when the designers modify the original design to the specifications of the VE alternative proposal.

The availability of intent makes the Recommendation phase easier. The traceability of the design development and the VE alternative development shows the appropriateness of the alternative to the owner. Thus, owner's acceptance of VE proposals is more likely. The externalization of intent information allows owners to evaluate the implemented alternatives well after the facility was constructed and even up to the retirement of the facility.

COMPUTER-AIDED VALUE ENGINEERING

This section discusses the framework for a computer-aided value engineering (CAVE) system. This framework comprises of descriptions of: (1) representation paradigms capable of covering the entire VE process, from the information phase to the post occupancy evaluation phase; and (2) applicable computer technologies to be used in each of the VE phases.

A representation paradigm capable of supporting the VE process must be able to support the design process as well. The information the VE team need for the VE study is essentially owner's intent and designer's intent. Object-oriented programming concepts have been identified as being capable of capturing and manipulating design intent. The Skull Object Space (SOS) framework illustrates this point, De La Garza and Oralkan [3]. This paper envisions a proposed CAVE system using the SOS framework only as one part of an integrated model-based reasoning strategy. Model-based reasoning is the integrated usage of rule-based, frame-based, and object-oriented systems, computer-aided design and drafting (CADD) systems, and database management systems.

Rule-based systems use an inference engine to control a set of rules. This control strategy is the main difference between rule-based systems and conventional programming. In rule-based systems, rules are instantiated opportunistically while in conventional programming, rules are executed sequentially. This ability to fire rules in an opportunistic manner based on the current context is of great importance to a CAVE system since design and value engineering are context sensitive tasks.

Frame-based systems use attribute-value pairs to store information about objects. Examples of these information are geometric properties, non-geometric properties, and intent. These object attributes or slots can be inherited from their parent objects. This inheritance capability allows for efficient data storage extremely needed for a CAVE system where captured intent should keep growing throughout the life-cycle of the facility. Object-oriented systems use message passing and methods to allow objects to act. Message passing involves sending control messages to methods. Methods are very small procedural tasks that are associated with particular attributes of

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objects. Methods are similar to attributes in that they are both entirely contained within an object. Being encapsulated within objects allows methods to be inherited from parent objects. This inheritance capability allows an object instance to reason about itself independently from the other object instances. This capability is of major significance to a CAVE system since it allows object instances to deduce their function based on their own attributes.

CADD systems are predominant in the architecture-engineering sector. Many of these firms use CADD systems to help in their design process. As such, an object-oriented CADD system seems the logical method to use in capturing design intent information from the designers as they go about the process of design. Further, the use of object-oriented knowledge system frameworks for intent elicitation necessitates the need for a CADD system to be object-oriented. Database management systems are still required in a CAVE system. Users may have a number of existing databases containing information on previous projects which they use as an aid in designing their current project.

Control mechanisms are necessary in the proposed CAVE system to give structure in the design intent elicitation task. An unstructured or poorly structured user interface for capturing intent will only frustrate designers trying to document their design process. This results from the fact that designers will need to answer questions which may or may not be related to the context of the current design task. Further, this user interface should be as non-intrusive as possible to avoid frustrating the designer. One way to do this is by allowing the designers to toggle on and off the control mechanisms used in eliciting intent. Designers will have the choice of either expressing intent as he or she creates an object, or expressing intent until after he or she finished creating a group of related objects.

The use of a model-based reasoning strategy allows the use of a variety of computer techniques in each of the different VE phases as shown on the following discussion and depicted in Figure 1.

<u>Information Phase</u>
Object-oriented CADD software together with a knowledge-based expert system (KBES) will unintrusively capture the owner's and the designer's intent. KBES technology will reason with the captured intent and relate it to the VE functionality technique. Spreadsheet technology will calculate material, construction, operation, maintenance, and other life-cycle costs for the various objects in the CADD model. Spreadsheets will also generate various cost models for the facility. Some cost models are: system assemblies model (Uniformat), construction trades model (Masterformat), and functional use model, Dennis [5]. Case-based reasoning (CBR) and Database technologies will retrieve historical data about functional worth or the least cost of an

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COMPUTER-AIDED VALUE ENGINEERING

VALUE ENGINEERING PHASES		Activity	Computerization
	Information Phase	Communication of design development knowledge from the A/E team to the VE team.	Object-oriented Computer-Aided Drafting and Design tool and Knowledge Based Expert Systems to capture design intent.
		Breakdown of the project into its functional specifications.	Knowledge Based Expert Systems to reason with the captured design intent and relate them to the VE functionality technique.
		Determination of the projected cost of the items performing the different functions.	Spreadsheets to calculate material, construction, maintenance, and other life-cycle costs, and generate various cost models.
		Determination of the projected worth of the items performing the different functions.	Case Based Reasoning and databases to retrieve historical data on functional worth.
		Sorting of items eligible for VE study based on cost-to-worth ratios.	Spreadsheets to calculate the cost-to-worth ratios for the different component items of the project.
	Speculation Phase	Creation of equivalent functional alternatives to the VE candidate items.	Suggestion of functional alternatives by a Knowledge Based Expert System using the Plan-Generate-Test, Blackboard, and Means-End strategies.
	Analysis Phase	Selection of VE alternatives that are more promising.	Knowledge Based Expert Systems, Spreadsheet, Database and Case Based Reasoning tools to aid in the selection process through the use of captured intent.
	Development Phase	Determination of the projected cost of the selected VE alternatives.	Spreadsheets to calculate material, construction, maintenance, and other life-cycle costs.
		Determination of the projected worth of the selected VE alternatives.	Case Based Reasoning and Databases to retrieve historical data on functional worth.
		Comparison of the cost-to-worth ratios of the selected VE alternatives and the original design.	Spreadsheets to calculate the cost-to-worth ratios for the different alternatives to compare to the original design.
	Recommendation Phase	Presentation of alternatives to the owner or the A/E team for implementation.	The use of the Object-Oriented Computer Aided Drafting and Design tool, Knowledge Based Expert Systems, Spreadsheets Databases, and Case Based Reasoning for a well structured presentation on the VE recommendations.
	Post-Occupancy Evaluation Phase	Post-occupancy evaluation of the actual cost of the implemented alternative to validate the projected costs and form the basis for the projected worth.	Spreadsheets to calculate actual material, construction, maintenance, and other life-cycle costs. Databases and Case Based Reasoning to update historical data on functional worth.

Figure 1. Spectrum of VE phases and their suitability for computerization

alternative capable of performing the same function. Spreadsheets will calculate cost-to-worth ratios for different component items of the project.

Speculation Phase
KBES technology employing the Plan-Generate-Test, the Blackboard, and the Means-Ends strategies will generate functional alternatives.

Analysis Phase
Spreadsheet, Database, CBR, and KBES technologies will assist the VE team in evaluating the ideas generated in the speculation phase.

Development Phase
Object-Oriented CADD and KBES technologies will assist the value engineer in generating a new design for each alternative slated for further development. Spreadsheet, Database, CBR, and KBES technologies will assist the VE team in evaluating the probable performance of these ideas.

Recommendation Phase
Object-Oriented CADD, KBES, CBR, Spreadsheet, and Database technologies will present, justify, and sell the recommendations made by the VE team.

Post-Occupancy Evaluation Phase
Spreadsheet technology will calculate actual material, construction, operation, maintenance, and other life-cycle costs. Database and CBR technologies will update historical data on functional worth.

ONGOING SOFTWARE DEVELOPMENT

A prototype system for a CAVE system is being developed. This prototype system runs under the Windows environment to take advantage of its multi-tasking and dynamic data exchange (DDE) capabilities. Through multi-tasking, different applications can be in operation concurrently. Through DDE, data in the different applications are linked together such that a change implemented in one application is immediately reflected in the other applications.

This prototype system uses three Windows applications - AutoCAD, Kappa, and Excel. AutoCAD is the software that stores the graphical representation of the design. However, AutoCAD is not object-oriented. As such, a module called CIFECAD, Ito et al. [12] is loaded on top of AutoCAD. CIFECAD attempts to create an object-oriented flavor for AutoCAD. Kappa is an object-oriented knowledge base engine that captures and reasons with design intent. Excel is a spreadsheet that Kappa manipulates to present cost models and retrieve functional worth values.

The information phase benefits most from the externalization of design intent. As such, the CAVE prototype system development is currently limited to the design stage and the information phase of value engineering. The following paragraphs discuss the preliminary functional specifications of the prototype system.

Owner
Intent externalization in the design stage starts with the knowledge-based engine, Kappa, asking information about the owner's intent at the project level (e.g. building type and capacity). If the owner has any lower level requirements (e.g. space allocation), he or she can also enter this in the knowledge base.

Designers
The designers retrieve the owner's intents though the user interface of Kappa. Knowing the scope of the project, the designers launch the graphical design interface, AutoCAD, to start designing the computer model of the project. Through the use of CIFECAD, designers start creating objects in the model space. As objects are created, the inference engine checks the value of the intent capture toggle switch. If the intent toggle is on, Kappa asks the user a context sensitive question regarding the intent. If the intent toggle is off, Kappa stores the newly created objects in a stack for later processing by the designer. The designer's responses to these intent questions form the input to Kappa. Kappa reasons with these data to generate more specific intent questions or to check the validity of these data against the constraints (e.g. owner's requirements).

Value Engineers
Value engineers use the Kappa interface to retrieve owner's and designer's intent. Value engineers can instruct Kappa to display functional diagrams as well as cost models. Kappa evaluates captured owner's and designer's intent to create a functional diagram. As for cost models, Kappa transfers data to an Excel spreadsheet capable of displaying the required cost model. To retrieve designer's intent, value engineers use AutoCAD to select or pick the objects they want to know about. Once an object or a group of objects are selected, Kappa analyzes the similarities of these objects to display information the value engineer may want. If this is not what the value engineer wants, or if Kappa cannot analyze what he or she wants, the value engineer can instruct Kappa to display certain kinds of information (e.g. specific object attributes). After having this information displayed, value engineers can attach VE speculations to these objects as necessary.

The prototype system to date is capable of initiating communications and data links to each of the three Windows applications. It is also capable of a limited owner's intent extraction. Objects can also be created in AutoCAD and linked to Kappa's object tree where non-geometric attributes and design intent are stored.

CONCLUSIONS

The development of a CAVE system as postulated in this paper is consistent with meeting the short-term needs of the architecture-engineering-construction industry. The ability to communicate intentions to the other participants involved in the project is one of these short-term needs. This paper focused on the designer-value engineer communication link and how computer technologies can assist in this communication link. In capturing and using design intent, designers are, in essence, doing value engineering concurrent with their design development efforts. Also, as the intent of one designer (e.g. architectural) is captured and externalized, other designers (e.g. structural, mechanical, electrical, civil) can react on the effects of the architect's design decision on their particular design. This concurrent engineering effort ensures that the different sub-systems of the building perform as one well-integrated unit performing in accordance with the owner's specifications and expectations. As such, the value engineering philosophy as we know it today, becomes embedded as an integral part of the future design process.

The externalization of design intent can also be extended to cover construction intent and facility operation intent. Facility-specific intent does not end in the design stage, rather it continues on until the facility is demolished. As owners become more demanding on the quality of facility construction and operation, intent gathered from the design stage becomes very important in the construction stage. Further, intent taken from the design and construction stages, as well as prior facility operation actions, are essential in the operation stage. As such, the externalization of design intent for use in value engineering forms the foundations to a computer-integrated facility life-cycle concept.

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