ON THE AGENDA OF DESIGN MANAGEMENT RESEARCH

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ABSTRACT

We propose an agenda for design management research. That agenda is based on a new conceptual foundation for operations management. Design processes can be conceived in at least three different ways: (1) as a process of converting inputs to outputs, (2) as a flow of materials and information through time and space, and (3) as a process of generating value for customers. All three conceptions are appropriate and necessary. However, the conversion model has been dominant in the AEC (architectural/engineering/construction) industry until very recently. We review current thinking and practice of design management, suggest fundamental hypotheses, then propose an agenda for design management research based on those hypotheses.

KEY WORDS

Design management, concurrent engineering, value management, project management

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INTRODUCTION

ON THE NATURE OF DESIGN MANAGEMENT

The design of AEC facilities poses difficult management problems. While site construction can operate on a definition of quality as conformance to requirements, design must produce those requirements from a careful identification of customer needs and meticulous translation of those needs into engineering specifications. There are multiple customers of the design whose voices must be heard and whose needs are often conflicting. Tradeoffs between multiple, competing design criteria must be made throughout the design process, often with inadequate information and under intense budget and schedule pressure. Many design decisions are reciprocally independent, making the management of work flow among the various specialists especially important and difficult. Early design stages are notoriously hard to evaluate and control against progress milestones. Lacking physical deliverables such as drawings, it is difficult to measure the amount of work completed and remaining on any given task and consequently in the project as a whole. To make matters worse, projects are increasingly subject to uncertainty because of the pace of technological change, the rapid shifting of market opportunities, and the inability to keep pace with relentless pressure to reduce time and cost.

CURRENT PRACTICE OF DESIGN MANAGEMENT

Generally, the management of design and engineering is felt to be problematic in AEC projects. Coles (1990) found that the most significant causes of design problems are poor briefing and communication, inadequacies in the technical knowledge of designers and a lack of confidence in preplanning for design work. Common consequences included slow approvals from clients, late appointments of consultants, and inadequate time to complete design documents carefully. In his study on technical design of buildings, Sverlinger (1996) found that the most frequent causes for severe deviations during design were deficient planning and/or resource allocation, deficient or missing input information, and changes. In his study of construction defects, Josephson (1996) found that when measured by cost, design-caused defects are the biggest category. From design caused defects, those originating from lack of coordination between disciplines are the largest category.

AGENDA FOR DESIGN MANAGEMENT RESEARCH

In this paper, we suggest that one major reason for the poor level of design management has been the lack of solid conceptual foundation. This shortcoming has made it difficult, both in practice and in research, to acquire the necessary understanding on the management issues of design.

We first review the mainstream programmes to improve design management, as evident in state-of-the-art practice and research. Then we present the new conceptual framework of design management. We analyze the implications of this framework regarding design management. Lastly, we call for systematic research collaboration for the sake of improvement of design management.

STATE-OF-THE-ART OF DESIGN MANAGEMENT

In this section, the mainstream responses to the problems of design management are reviewed and evaluated.

DESIGN MANAGEMENT AS PROJECT MANAGEMENT

The conventional view on design management has essentially been the same as in project management. Thus, the problems of design would be caused by lack of application of project management methods, which, in light of empirical research, is at least partially true. This is the view promoted by the project management community (PMI 1996), and also largely by "best practice" guidebooks for construction design management (Gray et al. 1994, CH2MHill 1996).

However, project management concepts and techniques have proven incapable of solving the difficult problems of design management. The main reason for this is that project management concepts are rooted in the conversion model (for more detailed treatment, see Cooper 1993, Koskela 1996). The heart of the conversion model is the assumption that the work to be done can be divided into parts and managed as if those parts were independent one from another. Management techniques such as work breakdown structures and earned value analysis belong to this conversion model. Work breakdown structures are driven by scoping and budget concerns and have the objectives of insuring that all the work scope is included in one of the parts, and of allocating costs to each part such that the rollup yields the total for the project. This division into parts is necessary in order to allocate responsibility to internal or external work centers, which can subsequently be controlled against scope, budget, and schedule commitments. This is fundamentally a contracting mentality, which facilitates the management of contracts rather than the management of (design) production.

CONCURRENT ENGINEERING

Concurrent engineering (CE) is a conceptualization of the product development process found in the world of product design and manufacturing (Ulrich and Eppinger 1995). Although there is some range of meanings, generally "concurrent" refers to the simultaneous or integrated consideration of multiple design criteria expressing the needs or wants of multiple stakeholders.

The traditional method of design is sequential rather than concurrent. The architect develops a concept and hands it over to the structural engineer. She may or may not be able to engineer the facility as conceived by the architect, so reloops and revisions are common.

Concurrent engineering concepts have just begun to enter the AEC community. One early emphasis has been on application of information technology rather than reconceptualizing the design process (cf. Anumba and Evbuomwan 1997). Another related trend is the use of cross-functional teams in construction projects; such names as partnering, teaming, etc. are used in characterizing these initiatives. However, for example partnering alone has turned out to be insufficient for more radical changes of mental models or management of production (Howell et al. 1996). Instead, recent research shows that a combined application of this kind of CE methods brings about significant benefits (The Business Roundtable 1997).

All in all, in spite of a promising application of certain CE ideas, presently there is no generally accepted model of concurrent engineering in AEC projects.

DESIGN PROCESS MODELS

Phase models are high-level flow models that provide the basis for managing the movement of incomplete work through the various design specialities. Various phase models of the design process have been developed (Roozenburg and Eekels 1995), including the architectural model which identifies the phases of programming (although, strictly speaking, programming is considered to be a kind of business management or predesign function rather than design proper), schematic design, design development, and construction documents. Phases are distinguished in terms of documents produced, each of which are an attempt to get commitments to a progressively more detailed design in hopes of preventing backtracking. This reliance on drawings is a consequence of the architect's focus on the shaping of space. The essential design process that occurs within each phase is conceived as a series of creative acts.

Engineering-driven design processes differ in the absence of a significant architectural component. With the exception of bridges, which can be among the most beautiful things made by humans, AEC facilities other than buildings place a substantially lesser value on aesthetics. The process for designing highways, tunnels, sewage treatment plants, and refineries is nonetheless also conceived in terms of a phase model very similar to the architectural model. However, the fundamental design cycle is conceived rather in terms of problem solving than in terms of creativity, even though creativity is often involved in the generation of alternative possible solutions.

Interestingly, neither of these AEC models explicitly present the process of generating and applying design criteria for both product and process. The process industries, especially in the U.S., have aggressively promoted the concept of design constructability (O'Connor 1993). However, constructability criteria are typically applied after possible designs have been developed rather than integrated into the design process proper. Further, constructability is only one of many relevant process criteria.

DESIGN AS VALUE MANAGEMENT

Value concepts appear in the form of predesign phases that identify design criteria and also in the methodology of value engineering. The architectural community recognizes the importance of programming as an initial phase defining customer needs and other requirements the design must satisfy (Palmer 1981). However, there is a tendency to disregard or underplay the extent to which value to the customer is created rather than simply revealed by questioning. This may be a consequence of the designer's concentration on what is considered to be design proper and a consequent haste to get on with the real work.

However, reflection reveals that value is generated through a type of learning process, which can be conceived as a dialogue between ends and means. A customer may want a facility for generating rental income from users of commercial office space, and may believe initially that such a building should have a certain visual appearance, have a specific number of floors, and be located in a certain place. As the consequences of her desires are revealed through determination of costs and requirements, the customer's desires may change. They may change also because alternative design solutions are revealed or because analysis shows a flaw in the assessment of the business opportunity. One purpose of the traditional design phasing is to contain a natural tendency for this "conversation" to continue by placing check valves in the process to prevent backflow. This technique works effectively only if the dialogue has progressed to the point of choosing from among alternatives. Conceptualizing value as a generation process and developing effective process tools is much needed by the AEC industry.

Value engineering comes in several varieties. The first variety is an offshoot from the design-bid-build project delivery method, in which the constructor can only contribute design ideas after the bid documents have been produced. Within the design process, value engineering has been advocated as a kind of peer review process, in which the design is critiqued at various stages of development, usually by an outside team. Both these varieties present value management as something that occurs as a kind of critique of a design already produced. One might reasonably ask what's so valuable about doing it over again.

Yet a third variation exists in the U.K., perhaps best represented by Green (1994), who advocates placing value generation at the center of the design process. This is a proactive approach not subject to the criticism made above of value engineering, and is a significant contribution to reconceptualization of the design process.

Curiously, recent up-to-date value management guides (Creating value…1996, Kelly and Male 1993) do not recognize Quality Function Deployment, which in manufacturing oriented product development is one cornerstone of value management.

NEW ORGANIZATIONAL FORMS AS A SOLUTION

The separation of design and construction has long been presented as the root problem of construction. Thus it is no wonder that great expectations have been attached to design-build procurement of construction projects, where these two stages are organizationally integrated from the outset.

However, two recent empirical studies data (Bennett et al. 1996, CII 1997) show that the design-build procurement alone does not produce significantly better results than conventional procurement methods. It is marginally better in several respects, but – in opposition to the views presented in these two studies—we don't find these differences to be significant.

Based on our observations, the problem of design-build seems to be that the potential of organizational integration is not well utilized: control and improvement of the design process remain insufficient, even if the process structure is better, and at the end, there is not too much difference in process capability in comparison to the conventional organization.

INFORMATION TECHNOLOGY SUPPORT FOR DESIGN MANAGEMENT

Interest in information technology support for design and its management has been considerable both in practice and research. Information models for both product and process make up one important development area.

The increasing use of information technology has certainly brought about benefits. However, in practice, the application of information technology rarely has produced a qualitatively new design process. Regarding this disappointingly small impact of information technology, interesting direction is given by Fenves (1996) in his recent, noteworthy paper. He calls for a science base of application of information technologies in civil and structural engineering. One component of this science base would deal with the understanding of the processes of planning, design, management, etc. that engineers use:

> *"we need to agree on an intellectual framework, in order to create a scientific understanding or abstraction of engineering processes in practice."*

This can be interpreted as follows: The bottleneck in construction computing is not in deficient capabilities of information technology in general or its specific applications, but in deficient understanding of engineering and construction. Also Sriram (1998) suggests that researchers in information technology should actively participate in developing a rigorous theory of design.

CONCLUSIONS

The state-of-the-art approaches to design management contain many interesting and seemingly effective new features. However, these approaches are fragmented and they lack a solid conceptual foundation. This has become a barrier for progress.

TOWARDS NEW UNDERSTANDING OF DESIGN MANAGEMENT

As a step towards a more solid conceptual foundation of design and engineering, we suggest viewing engineering simultaneously in three ways: as conversion, flow and value generation. This conceptualization of design (Table 1), derived from analysis of various concurrent approaches, has been presented in more detail in (Koskela and Huovila 1997).

The conventional conceptualization of engineering is based on viewing engineering as a conversion. The conversion view is geared towards getting the engineering task done. The well-known practices of Work Breakdown Structure (WBS) and Critical Path Method (CPM) are used for this purpose. However, several significant features, like time and customer, are abstracted away in this conceptualization. The flow and value generation views are neglected. This is reflected in the empirical observation that two kinds of problems beset conventional engineering: weak process and weak co-operation (Clausing 1994). Thus engineering, managed in the conventional method, tends to become inefficient and ineffective.

In the flow view, the basic thrust is to eliminate waste from flow processes. Thus, such practices as reduction of rework, team approach, releasing of information in smaller batches to following tasks, for example, are promoted. A primary tool for representing and managing flows is the Design Structure Matrix method.

In the value generation view, the basic thrust is to reduce the value loss (in relation to the best value possible) from the point of the customer. Such practices as rigorous requirement analysis, systematized management of requirements during engineering, and collaborative iterations for improvement are forwarded. Among the related tools, Quality Function Deployment is one of the most promising.

What is needed is a management philosophy and tools that fully integrate the conversion, flow, and value views. The product development processes employed by firms designing and manufacturing discrete products (automobiles, printers, toasters, etc.) offers advice, especially in the area of value; identification of customer needs and translation into engineering specifications (Ulrich and Eppinger 1993). Recently also the flow view has explicitly been discussed in this domain (Goldratt 1997, Reinertsen 1997).

Table 1. The conventional engineering approach is based on the conversion view; the concurrent engineering approach stresses the flow view and the value generation view, in addition to the conversion view (Koskela and Huovila 1997).

	Conversion View	*Flow View*	*Value Generation View*
Conceptualization of Engineering	As a conversion of requirements into product design	As a flow of information, composed of conversion, inspection, moving and waiting	As a process where value for the customer is created through fullfilment of his requirements
Main Principles	Hierarchical decomposition; control and optimization of decomposed activities	Elimination of waste (non-conversion activities); time reduction	Elimination of value loss (achieved value in relation to best possible value)
Methods and Practices	Work breakdown structure, Critical Path Method, Organizational Responsibility Chart	Rapid reduction of uncertainty, team approach, tool integration, partnering	Rigorous requirement analysis, systematized management of flowdown of requirements, optimization
Practical Contribution	Taking care of what has to be done	Taking care of that what is unnecessary is done as little as possible	Taking care of that customer requirements are met in the best possible manner
Suggested Name for Practical Application of the View	Task management	Flow management	Value management

OBJECTIVES AND TASKS

INTRODUCTION

If we accept the framework presented above as a starting point, what research tasks lie ahead? Obviously, we should create understanding about the concepts and causal mechanisms involved in each view and on that basis develop methods and tools. However, beyond that, we should develop understanding on the interaction of these views and on the associated methods needed.

In general, it must be said that there is little empirical data on what actually happens in design management. Thus, beyond experimentation with new methods and tools, exploratory research is needed.

In the following, we present open questions and a number of hypotheses as an agenda for research. The hypotheses are selected in such a way that they can provide a basis for experimentation and method development after having been validated.

UNDERSTANDING COMMON PRINCIPLES IN VIEWS

Are there common principles in all these three views? While there is no definite answer yet, we are tempted to develop two hypotheses by induction. Historical analysis reveals that the conversion view has developed, firstly, through explicit representation of the design process, aiming at clarity and transparency, and secondly through introduction of systematic methodologies for planning, controlling and monitoring the design process. An example of the first feature is provided by Work Breakdown Structure, and of the second feature, the Critical Path Method.

Support for the thought that similar principles also apply in the two other views is given by such methods as flow modeling (in the flow view) and Quality Function Deployment (in the value generation view), which actually contain both discussed features. Thus, we could formulate following hypotheses:

- **Hypothesis 1.** Transparency of the design process from one view, achieved through explicit modeling and other means, is conducive to a successful outcome of design from that view.
- **Hypothesis 2.** Use of systematic methodologies to manage the design process from one view is conducive to a successful outcome of design from that view.

For validation of these hypotheses, comparative case studies and experimentation are needed.

UNDERSTANDING EACH VIEW

Obviously, we need to create understanding and to structure knowledge on each view. Concepts should be clarified, methods developed and tools tried out.

The **conversion view** has been used a long time, and thus it should be the best understood view. However, often it is not being systematically used in AEC design management. Research is needed to discover the barriers for use of the conversion view in design management. Also, there might be room for refinement and augmentation of the methods and tools in this view. For example, Walker (1996) suggests introducing new methods for more accurate description of each participant's relation to each task.

The understanding of the **flow view** is becoming mature in the context of (physical) production management. This understanding can apparently be used also for design, when minding the differences between physical production and design. The interesting possibilities and implications of seeing design from a production management perspective are explored in more detail in a separate section below.

The **value generation view** is the least understood among the views. Thus, at the outset, exploratory research is needed besides experimentation with associated methods.

UNDERSTANDING THE INTERACTION OF VIEWS

How do the views interact? Actually, our understanding of this question is based on the predominance of the conversion view. Related empirical observations are discussed below.

First, it is a commonly occurring phenomenon that in task management, often too little time is reserved for needs analysis and other issues of value management. This might be because value management is simply not conceptually captured in task management, based on the conversion view. There is also a tendency to segment and rigidly sequence design work; e.g., the task of producing a design brief or project definition is typically given to a different group than that tasked with producing a design to the stated criteria. An alternative would be to have the customer process pull what it needs from the supplier process. Another alternative, not necessarily exclusive, would be to have the design team interact directly with clients and other stakeholders to develop design criteria, and to have clients and stakeholders participate throughout the design process in the ongoing dialogue between means and ends that constitute the value generation process. Such possibilities emerge from the flow and value views, not from the task view.

Second, in task management, the need for joint solution by designers of different disciplines, arising either from flow view (i.e. block of interrelated tasks in a DSM matrix) or value view (different product subsystems contributing to one requirement) is usually not recognized (that is, there are no joint assignments).

Third, the traditional design (also called point-to-point design) gives priority to task management and puts value management into secondary position. The common practice of design is that each task produces a single design solution. In complex design situations, it is usual to iterate on one alternative until a satisfactory solution emerges. It is assumed that each task can find the best solution in one shot. In fact, the conversion and flow views are dominating in such practice, at the cost of the value view: the conversion view stresses getting each task done, and the flow view presupposes each activity to have a short and predictable duration. In contrary, in the value view, the primary issue is in finding a still better solution in each task, using all the time available. This conventional practice, which can be called point-to-point design, is predominant in the current understanding of concurrent engineering. However, recently it has been pointed out that an alternative, set-based concurrent engineering is being used by one company, namely Toyota (Sobek & Ward 1996). Here, designers explicitly communicate and think about sets of design alternatives. They gradually narrow the sets by eliminating inferior alternatives until a final solution emerges. Thus, set-based concurrent engineering represents an approach in which conversion, flow and value views are pursued in a more balanced way.

Fourth, in the absence of flow management concepts, the available means for controlling production and design processes shrink quickly to contracting and associated techniques. Controlling is reduced to controlling behavior, namely performing to one's commitments. Through the contracting lens, it is difficult to see any but the moral world of responsibility and blame. The empirical world of flows, rates, qualities, and quantities disappears.

On the basis of these observations, we formulate the following hypothesis:

- **Hypothesis 3.** In design management, the management needs arising from the three views should be integrated, aligned and balanced.

This hypothesis might be validated by re-assessment of prior research and by experimentations.

However, there are grounds to suspect that the interaction of the three views is even stronger than presented above. The neglect of flow and value management, implicit in the traditional task management-dominated approach, leads often to problems in task management, too. For example, poor definition of needs (domain of value management) causes disruption through untimely design changes to task and flow management. Thus, we formulate:

- **Hypothesis 4.** For achieving a successful outcome of design from one view, orderly management of design from the two other views is necessary.

This hypothesis could be validated through case studies on design projects, evaluation of prior research, and statistical studies.

MANAGEMENT OF DESIGN PRODUCTION

As a contribution to the integration of all three models, the following applies the flow model to the design and management of AEC facilities. Conceptualizing the design process as a flow of information lends itself to reducing waste by minimizing time information spends waiting to be used, time spent inspecting information for conformance to requirements, time spent reworking information to achieve conformance, and time spent moving information from one design contributor to the next. Further, and even more important than reducing the cost and time of design, conceptualizing the design process as a flow of information allows coordination of interdependent flows and the integration of design with supply and site construction.

In the conversion view, production management is the ‘local’ responsibility of those to whom the various parts are assigned or contracted. If everyone meets their contractual obligations, the project performs successfully.

Earned value analysis is a tool, developed within the conversion view, for controlling projects through productivity and progress. By itself, it would have the design manager believe that a project is performing well if it is earning labor hours at the budget unit rate and also earning sufficient hours to maintain a scheduled earnings plan expressed as percentages of earned hours to total hours to be earned. The obvious weakness in this control mechanism is that projects may exhibit budget productivity and be on the earnings plan, but not be doing the right work in the right way at the right time. Consequently, quality control is invoked as a separate control mechanism, although often not controlling against the objective of expressing customer needs in engineering specifications, but rather controlling against the objectives of avoiding calculational and dimensional errors. As for the issue of the timing of work, it has proven necessary to establish schedule milestones to enforce adherence to a work sequence. These rear guard actions are frequently ineffective against the dominant progress and productivity controls, which consequently cause managers to throw the lever in the wrong direction because they misevaluate actual project performance.

Managing work flow consists in controlling the movement of work from one production unit to the next within and across phases. Work flow management is facilitated by effective work structuring, which divides the work to be done at the ‘natural joints’ revealed by flow analysis, as opposed to the traditional work packages structured to facilitate cost control. Design phases are provisionally conceived to include development of design criteria for product and process, definition of the design space, selection of design concept(s), selection of systems and technologies, detailed integration of systems and components, production of construction and fabrication directives, field support (responding to requests for information, reviewing submittals and shop drawings), startup, and learning from post-occupancy feedback. (The utility and appropriateness of alternative conceptions of design and construction phasing will be considered in exploratory case studies.) Within construction, assembly chains can be identified and control applied to the flow of work among the production units serving as 'work stations' in those assembly chains. A production unit is an individual or a group responsible for a certain part of the work to be accomplished. Production units usually represent different specialists among whom work flows in various ways in order to be completed.

Work flow control is achieved by requiring the satisfaction of previously specified constraints prior to release from one production unit or phase to the next (quality) and by adjusting sequencing and capacities to maintain scheduled pace (quantity). Production unit control is the selection, sequencing, and sizing of assignments made to production units. Selection is to be made only from work that has been released by an upstream production unit, and only if a downstream production unit is or will be prepared to further progress the assembly.

Although work flow management and production unit control originated in manufacturing, these techniques take on a different character in production systems like design and construction in which work selection is driven by directives rather than by predetermined routings between machines. Many AEC production units have considerable discretion in their choice of what work is to be done at any point in time. Helping production units make the right choices and keeping all such choices synchronized is one of the major objectives of production management. Other key objectives include matching resource capacity to work flow and improving plan reliability.

The Last Planner concept has been used in construction to improve plan reliability by controlling the quality of assignments (Ballard and Howell 1994). Initial applications to design management have been promising (Koskela et al. 1997). Subsequent work will include further experimentation with such concepts and techniques in design management.

We propose research questions explicitly for the management of design from a production management perspective: (1) How best structure a project or projects organizationally to facilitate value creation and waste reduction throughout the entire production system? Included here are commercial relationships among participants and specialists, and also the issue of tiering; i.e., who should be contractually subordinate to whom? Should installers be first tier or should engineers? What's the best role for architects? (2) At what phases of design development should the various specialists be involved? For example, should fabricators and installers be included in conceptual design? (3) What techniques are most effective for the integrated design of product and process? (4) What techniques are best for production control beginning in the design phase of projects?

CALL FOR COLLABORATION

It is not an exaggeration to say that design management is a major bottleneck and root cause of problems in the AEC industry. However, we feel that design management can be rapidly improved if integrated efforts are directed to explore the domain, experiment with tools, and validate hypotheses and theories.

The authors invite all interested to collaborate within the conceptual framework presented in this paper, as well as improving the framework. While the practical details are still subject to discussion, the authors suggest starting a loosely coordinated international project for design management research. National projects, among which coordination and exchange of information would be organized through e-mail and an annual meeting, for example in association with the IGLC annual meeting, would be the main force in such an effort.

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