Toward Understanding of Product Innovation Process in Construction

By C. H. Nam[1] and C. B. Tatum,[2] Fellow, ASCE

Abstract: The peculiar characteristics of the products and the technological constraints of construction significantly differentiate it from manufacturing; this suggests that the process of innovation and the factors governing this process will differ. Based on an investigation of several product innovations in construction, this paper describes the characteristics of four key actors that play important roles in the innovation process in construction and the relationships among them. These actors are owner's demands, problems, designer's bank of technology, and contractor's process technology. This effort is the first step toward deciphering the mechanism of product innovation in construction, which has been neglected by researchers despite its immense importance to technological advancement in this vital industry. The paper also develops practical applications to assist industry professionals attempting to increase the rate of product innovation and implications to structure future research.

Introduction

The U.S. construction industry, with business receipts for new construction put in place averaging about 10% of the gross national product (GNP) during the past two decades (MacAuley 1981; *U.S. Industrial* 1985), is obviously one of the crucial sectors of the economy. Construction is also one of the nation's larger employers. Additionally, according to the *1982 Census of Construction Industries* (1984), the construction industry is a major customer of the manufacturing, transportation, and services sectors.

This important sector of the economy faces productivity and competitiveness problems. Productivity growth in construction is far below the national average; in fact, the decline in construction productivity has been among the most serious in the U.S. economy, and only the mining industry has done worse in the last decade (Cremeans 1981). A number of hypotheses offer explanations for the decline in construction productivity (MacAuley 1981; Allen 1985; *Construction Productivity* 1986; Cremeans 1981). However, they do not explain why productivity in U.S. construction has deteriorated more than in most other industrial sectors. In 1982, the Business Roundtable (*Integrating* 1982) found that the U.S. construction industry is far less progressive than many other major industries in developing and adopting new technology. They concluded that this situation was one of the reasons for rapid increases in the U.S. construction costs. The National Research Council (*Construction Productivity* 1986) also found that inadequate research and development (R&D) and the slow adoption of new technology undoubtedly had been major factors, though possibly not the only factors, in the productivity problems of the construction industry.

The slow rate of technological advancement in construction has caused

[1]Res. Asst., Dept. of Civ. Engrg., Stanford Univ., Stanford, CA 94305-0420.
[2]Prof. and Assoc. Chmn., Dept. Civ. Engrg., Stanford Univ., Stanford, CA.

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is classified into three types: (1) Technology as object (all of the artifacts used, or operated, e.g., nail pots, brick kilns, hammers, bulldozers, real time data collection devices); (2) technology as process (the processes of making in the sense of materially fabricating, and using in the sense of operation, management, testing, service, maintenance, etc.); and (3) technology as knowledge (e.g., Coulomb's empirical laws).

In order to investigate the process of product innovation in construction, it is essential to observe the role of architects and engineers; the Department of Commerce classifies these firms as part of the service industry. Thus, not only the construction industry but also the architectural and engineering sectors of the service industry are relevant to our investigation. Throughout this paper, the writers will use AE&C industry for simplification.

Why Product Innovation Is Important for Construction

"Innovation" takes many different and complicated forms. One major distinction is whether the innovation produces a greater volume of output (i.e., process innovation, cost reducing in nature) or a qualitatively superior output from a given amount of input resources (i.e., product innovation) (Rosenberg 1982).

Many scholars have emphasized the importance of product innovation in long-term economic growth. For example, Schumpeter (1942) termed product innovation a fundamental impulse that keeps capitalism going. For Schumpeter, the economic progress does not consist of the price-cutting nature of process innovations among harness makers, but, in the long run, of the innovative acts of automobile manufacturers, who abolished harness making as an economic activity (Schumpeter 1942). Kuznets (1971) also pointed out the central role of product innovation in long-term economic growth. He argued that all rapidly growing industries eventually experience a slowdown in growth as the cost-reducing impact of technical innovation diminishes; therefore, continued growth requires the development of new products and new industries. Rosenberg (1982) advises that "to ignore product innovation and qualitative improvements in products is to ignore what may very well have been the most important long-term contribution of technical progress to human welfare. . . . To exclude product innovation is to play Hamlet without the prince."

Despite the importance of the AE&C industry in the national economy, the study of construction innovation has been relatively neglected by analysts of technology. Furthermore, in this neglected industry, product innovation—perhaps the most important contributor to the technological progress—is, surprisingly, the most neglected. It appears that most construction researchers as well as industry professionals have not recognized the importance of product innovation for the long-term health of the AE&C industry. Most of the active university research, for example, appears to have focused on process innovation or management (Oberlender 1987).

The consequence of unbalanced innovative effort in construction is clearly shown in a recent Office of Technology Assessment report ("International Competition" 1986) that assesses the strength and weakness of the U.S. AE&C industry. According to this study, U.S. AE&C firms are good in technology associated with the construction process [e.g., construction management, computer applications in design and construction, notably in computer-as-

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sisted design and drafting (CADD) and integrating engineering and management data bases], but not in improving the quality of products or developing new products (e.g., a new type of tunnel or bridge). The U.S. AE&C industry has emphasized technology that is easier and quicker to develop and has short-term benefits; and has paid insufficient attention to what has been, in the long run, the most powerful force for advancement. This critical need is the major theme of this paper: the process of product innovation is of salient importance to the long-term health of the AE&C industry and thus to the national economy, and yet we do not understand what makes it happen in the way that it does in construction.

Background Investigations of Innovation Process

This section reviews background research regarding the general nature of the innovation process, including its characteristics, major forces prompting innovation, and factors affecting the innovation process.

Characteristics of Innovation Process

Because there are few prior studies of product innovation in construction, it is natural to seek relevant theories from other industries. Most of the background research consists of investigations of product and process innovations in heavy and high-tech manufacturing. Quinn (1985) summarizes the characteristics of the innovation process as chaotic, individual motivated, opportunistic, customer-responsive, tumultuous, and interactive in its development. "The most innovative companies thrive in these chaotic conditions, while others stifle innovation with detailed planning and cumbersome procedures" (Quinn 1985). There are uncountable feedback activities involved in innovation process. Drucker (1985) considers innovation to be a major responsibility of management. He sees the process more as plain work than the play of genius. He strongly believes that a purposeful, systematic approach is the nub of all the innovations. Kline and Rosenberg (1986) claim that the systems that make up the innovation process are among the most complex known (both technically and socially), and the requirements for successful innovation vary greatly from case to case.

Forces Prompting Innovation

Researchers have long debated the relative importance of "market pull" as contrasted with "technological push" in producing innovations. Myers and Marquis (1969) investigated many examples and found that market is the driving force in the great majority of successful innovations. Others argue that the existence of a market is no guarantee that anyone will innovate. For instance, Holt (1983) insists that radical innovations are the result of technological impetus, whereas minor innovations that follow arise in response to market demand. A third view emphasizes the importance of both demand- and supply-side factors; the Organization for Economic Co-operation and Development (OECD) concludes that there can be no innovation without success in both market and technology (*Innovation* 1982).

The Role of Individuals

Many researchers stress the important role of key individuals. Quinn (1985) claims that the following type of individual is a crucial factor in the success of innovative small companies—"inventor/entrepreneurs" who tend to be need- or achievement-oriented, tend to be experts and fanatics, underestimate the obstacles and length of time to success, enjoy flexibility and quickness, and foresee tangible personal rewards if they are successful. In fact, the significance of the role of the entrepreneur was well recognized by Schumpeter (1942): "the function of entrepreneurs is to reform or revolutionize the pattern of production." Frequently, the term *champions* is employed to refer to the individuals who lead the innovation process. Arthur D. Little, Inc. (*From Vision* 1985) identified three types of champions who work together: the technical champion who carries an idea from the initial concept through development into a viable product or process; the business champion who provides a business framework for a technical idea; and the executive champion who sponsors the idea at the highest level, using his/her power to protect it, move it along, and seize the opportunity to exploit it.

While it is not yet known whether entrepreneurs or champions "are born, developed, or the results of serendipity and circumstance" (Tornatzky 1983), it is certain that the function of the inventors or champions must be linked with the entrepreneurial function, which includes "risk taking, the provision of capital, the development from idea or prototype to operational status, and the coupling of the marketplace with the inventor's concept" (Susskind and Zybkow 1978).

Organizational Influences. Organizational contexts (or environments) "significantly affect organizations' capacities for innovation through (1) constraints on resources; and (2) information required for making effective organizational decisions" (Tornatzky 1983). OECD (*Innovation* 1982) found that the larger firm is more able to afford the new investment for innovation and more able to tolerate the risk of adoption, whereas the smaller firm is more likely to value the technology, and has less complex decision-making processes. However, size has seldom been adequately conceptualized (Tornatzky 1983). Furthermore, Mansfield (1971) suggests that the size of firm has little effect on innovation, at least when a firm is above some threshold size.

Nevertheless, it is often reported that larger firms do not seem to develop a greater proportion of innovations, relative to their market share, than smaller firms (Utterback 1974). Many researchers found that small firms are better in producing innovation (*Innovation* 1982). In this context of organizational size, Utterback (1974) reports that "in mature industries, such as textiles, machine tools, and construction, innovation is more likely to come from smaller, new firms than from older, larger firms, as well as from firms in other industries."

Organizational rigidity is often mentioned as a barrier to innovation in larger firms. Putnam (1985) believes that bureaucratic rigidity and barriers should be eliminated for high-quality, trouble-free production. Whereas Quinn (1985) takes a vertical (or hierarchical) viewpoint in analyzing organizational barriers to innovation in large firms, Putnam (1985), using a horizontal viewpoint, finds structural barriers that prevent team spirit from crossing departmental lines. Thus, Putnam argues that it is no longer enough to design first and do manufacturing engineering and quality control later, asserting that traditional concepts of departmental and functional organization are obsolete. He suggests the integrated manufacturing concept, which is a way of bringing manufacturing engineering, quality engineering, and test engineering in on the design process from an abstract idea to a finished item. He names this simultaneous collaboration of specialized functions "work cells" or "group technology."

How Construction Differs from Manufacturing

The previous section reviewed various findings in the manufacturing industry regarding innovation process. However, the applicability of those theories to construction is questionable because the technological phenomena of the AE&C industry are different from manufacturing. Construction is not a mere deviation of manufacturing. The fundamental differences first stem from unique characteristics present in most constructed products: immobility, complexity, durability, costliness, and high risk of failure (Nam and Tatum 1988).

These characteristics of constructed products affect the extent of applicability of technology and technological development in construction. For example, due to the immobility of the constructed product, construction is mainly a site operation. Because of site operation, construction still does not enjoy the advantages of automated production process and the mass production system.

Construction is mostly a custom-order activity. Thus, the level of involvement and the role of buyers (i.e., owners in construction) both in the design and production processes is quite different. Whereas in manufacturing the role of buyers in the innovation process is generally passive in the form of "market demand" or "potential needs" to which innovators actively respond, in construction, owners are vital participants: they initiate and exert influences both on the design and construction processes from the beginning to the end.

The complexity of the constructed product and the high risk of failure create a need for numerous specialized professionals; this fragments the construction industry. Whereas product design is becoming an integral part of production management in manufacturing, in construction the product design function is normally separated from production; this may also significantly differentiate the nature of the innovation process.

The costly nature and the high level of responsibility for public safety attached to constructed products in the AE&C industry generally discourage the implementation of trial-and-error or action-biased methods, which is said to be one of the major strategies for innovation in other industries. The consequence of failure of a new product in the construction industry is generally higher than in manufacturing. Thus conservatism characterizes not only designers or producers but also buyers of construction. The reaction of the customers in construction to a novel product, a new type of house, for example, is generally cautious rather than stimulative.

These differences between the AE&C industry and the manufacturing industry in terms of the characteristics of constructed products, technological constraints inherent in them, the technological phenomena, and the composition of actors suggest that the innovation process will be significantly different in construction. Thus, it is inappropriate to try to adopt theories of innovation process developed from the manufacturing industry and blindly apply them to construction. These differences suggest the need for a specialized investigation of the process for product innovation for the AE&C industry. The following are the preliminary results of this research.

A Model of Product Innovation in Construction

The background research and the results of some case studies have led to the following description of how new constructed products develop: an initial model of the process of product innovation in construction. This model does not identify sequential steps in a process, but rather probes the nature of the actors and the relationships between them. The four key actors in the process of product innovation in construction are owner's demands, problems, designer's bank of technology, and contractor's process technology (Fig. 1).

Owner's Demands

Generally, the process of product innovation in construction starts from an owner's needs for a facility. This need is often technologically conservative and may change during project execution. The factors that induce or shape the owner's needs include various economic considerations, technological progress in construction (e.g., a new type of constructed product may motivate owners to discover new needs), and particular firms' reputations or their technological competence (e.g., designers often influence owners in shaping their needs).

The owner's role as initiator is a strikingly important difference of the

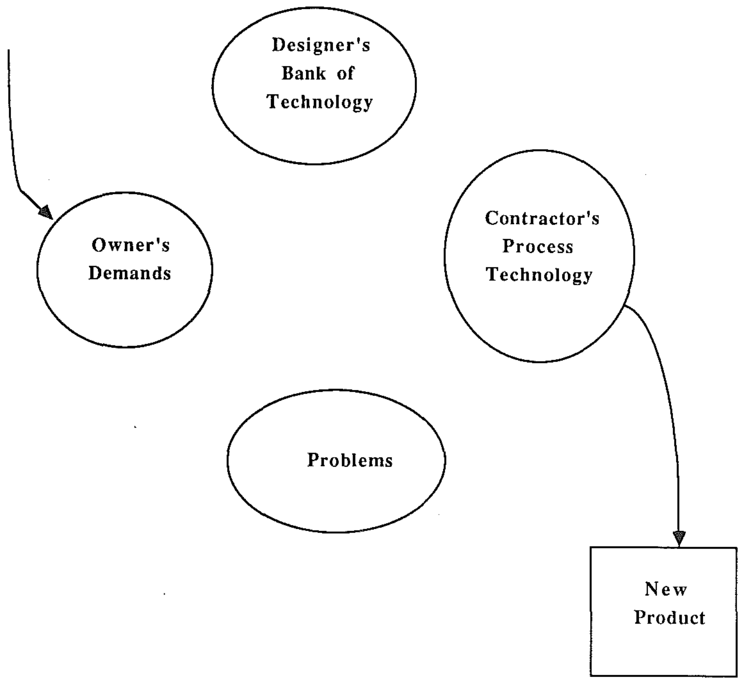

FIG. 1. Four Important Actors in Process of Product Innovation

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process of product innovation in construction as compared with the user's role in the manufacturing industry. Owners also establish the mechanism by which designers can communicate with contractors; they may make decisions on every detail throughout the project execution, and they sometimes share a high portion of risk. They are major participants in the projects, rather than just buyers of constructed products; this suggests that more involvement of the owner is necessary for better results in terms of product innovation.

Source of Owner's Demands

The variability of owner's demands depends on economic outlook. There is a clear tendency of the buyers of construction to place orders in times of confidence in the economic outlook and to withdraw when the outlook is doubtful. The reason for this is that products of construction are mostly durable so that it is usually possible to defer replacement of an existing structure. Another reason is that products of construction are usually costly investments. It is beyond the scope of this paper to investigate the relationship between the general economic situation and the rate of technological innovation in the construction industry. However, in times of general prosperity, the number of projects and total value of construction activities increase.

Characteristics of Owner's Demands

Most owner's demands are not static. They develop as design or actual construction proceed. This is because the owner's individual taste plays a vital role in shaping the product of construction and these tastes change as the product is visualized and moves through the concept formulation stage, preliminary design to the actual construction stage.

The characteristics of owner's demands can be generalized as the demands for a facility that is safe and meets economic, functional, and aesthetic criteria. However, typically, owners do not demand innovations in their facilities. A designer remarked: "The foremost important thing in this [designing] business is to do what your clients want you to do, and they should come back to you. [But] they do not want a revolutionary type monument. Most clients want just a functional and utilitarian structure that is safe and economical. [Thus,] we do not innovate for the sake of innovation itself." This designer's view is supported by an investigation of residential construction by Ventre (1979): So traditional are consumers' preferences when it comes to their own housing . . . many housing producers do their best to shield from view changes in technology that have already been absorbed into their production methods."

The owner's demands are the key initiator of the innovation process for a constructed product. This is, to some degree, equivalent to the market-pull concept in the sense of emphasizing demand-side aspect in the innovation process. However, the technical characteristics of this demand-side factor are different. Customers in the construction industry are technologically conservative. Furthermore, their demands are changing while their products are produced.

Designer's Role in Creating Demand

Owners contract with design firms in large part because of the firm's reputation and technological competence in handling owner's needs. It is extremely important to maintain a good reputation simply to get jobs in the design business, since competitive bidding is prohibited by most associations of design professionals. The design firm's reputation is built up through experience and performance, which most larger firms emphasize, or by demonstration of its key employees' technological capability, which many new small firms emphasize. A firm's reputation brings more volume of work to design, thus more chances to generate innovations to improve the quality of the product or to reduce the cost of the product. Then, in turn, these innovations contribute to building a good reputation. This is a cycle of innovations, reputation, and more jobs, often found in rapidly growing design firms.

Problems

Problems are uncertain things that designers/engineers/contractors cannot resolve with immediate applications of the technology they currently possess; problems require them to explore alternative technologies consuming resources. The designer needs either new technology or a creative reorganization of his existing technology to solve these problems. It takes time and energy to obtain new pieces of technology or to reorganize the existing technology. However, it is extremely important to recognize that problems make innovations. A saying from a designer emphasizes this fact: "If you face a problem, it's a good chance to innovate something. . . . In construction, problem is the mother of innovation."

Types of Problems

The problems designers face are generalized as follows:

1. Problems caused by unusual demands from owners: Sometimes owner's demands are not easily met with current state of the technology, the designer has, or it is too costly to do so. An imaginary example is a 1,000-story building.
2. Site and weather problems: Though the owner's demands are conventional, sometimes the site or weather conditions are abnormal; these create another type of technological challenge. The problem of heavy traffic on a bridge-repair site resulted in the design innovation of orthotropic steel decks. The problem of fragile soil on a tunneling site led to the multibored tunnel ("Many Bores," 1985).
3. Problems caused by constraints of schedule or budget: Often in construction the schedule or budget drive the designer to a product innovation.
4. Problems caused by contractors: Contractors seek cost savings in construction process. Thus they request changes in the plans. These are problems from the designer's point of view, since these changes require the designer's time and energy.

Characteristics of Problems

In most cases, problems steer designers toward technological challenge and eventually to product innovations. However, problems are not always clear and explicit. Often they are all vexingly mingled together so that they cannot be solved one by one. If the designer has a strong volition, or an attitude to find a better way is a part of a favorable organizational culture, almost everything can be defined as a problem, even though it can be easily solved by immediate application of current technology. Problems play an indispensable role in the development of successful product innovation.

Designer's Bank of Technology

To meet, or induce, these complex needs and problems, the designer's diverse mix of technology must be fully considered in the process. The term *designer's technology* here refers to the current pool of technology as object, technology as process, and technology as knowledge possessed by an individual designer or a design firm involved in the design of the project in question.

Nature of Designer's Technology

The technology as object includes any tools or equipment used in design (e.g., computers, pencils, etc.). The technology as process is the process through which the technology as object and the technology as knowledge are combined in order to prepare the plans and specifications effectively.

The designer's technology as knowledge can be further classified into four kinds: (1) The knowledge about construction materials that he has to specify or at least define (the type or strength needed) in the plan; (2) the knowledge about construction process—the methods for combining the materials, labor, equipment, tools, energy, and other resources needed to complete a constructed product; (3) knowledge on the restrictions on this use of construction materials and process (e.g., regulation, building costs, etc.); and (4) knowledge about design science (knowledge of behavior of the nature and knowledge of strength, stability, cost, aesthetics, and function of the combined materials in the nature).

These various kinds of designer's technology should be blended effectively and updated continuously. Thus, there are many implications in managing the designer's technology. Before describing these it is important to examine the sources of the designer's technology so that we can effectively keep the gates.

Sources of Designer's Technology

Eight sources are identified as the suppliers of depth, variety, and newness to the designer's existing technology. The first two are internal sources that need management decisions. The rest are external sources adopted through a mediation process. The eight sources are as follow:

1. Hiring people: The most effective way to move technology is to move people who have knowledge about technology, since creativity, education, training, and experience of the people constitute by far the largest proportion of information sources used in originating ideas for successful innovation (Utterback 1974).

2. Company R&D or contract with outside R&D: Few AE&C firms are concerned with R&D. The National Research Council found that "the U.S. construction industry [including owners, manufacturers of construction material and equipment, contractors, government agencies, and others] invests proportionally less in R&D than other U.S. industry" (*Construction Productivity* 1986).

3. Development of design science and design-process technology: Most development of design science occurs in academia. Examples include advanced analysis of seismic effects on building foundations, probabilistic design methods for building structures, and new design methods of concrete. But, until professional associations and regulatory agencies recognize and adopt these methods, designers usually do not use them. The advancement of design-process tech-

nology has recently focused on new applications of the computer in the design process; computer-aided design is an example.

4. Technological development in closely related industries and organizations: Many construction innovations have depended on the development or improvement of construction materials, equipment, and building machinery. Examples of new construction materials include glass, plastic, steel, and insulation materials. A good example of building machinery is the development of a safe and fast elevator, which allowed skyscrapers to be built.

5. Technological developments by other construction or design companies: Competitors may supply new technologies, on which small improvements can be added. An example is the "fin-back" bridge, which was developed by adding some other features (i.e., hiding cables inside the concrete) to the cable-suspension bridge concept ("Unique Bridge" 1986). Many innovations take little steps.

6. Construction process or design technologies from foreign countries: Numerous foreign construction technologies, mainly from Europe, have been successfully adopted in the U.S. construction industry. Tower cranes, the segmental bridge construction concept, many elements of concrete technology, and many others originated in Europe. There is strong need to watch overseas construction technologies.

7. Various technological developments from other industries: Often a particular innovation has to await the availability of a specific complementary input or component from other industries before it gains significance. For instance, designers should keep current regarding the development of telephone systems, local computer network systems, fire prevention systems, automatic doors or lifting technology (e.g., elevator and escalator), and light and strong materials developed in aircraft industry to properly design a building.

8. Regulation or building code changes: This is another form of technology as knowledge a designer should update continuously. This is not only to conform to the regulations but also to exploit their changes to design new, better products. One successful designer has a keen sense on the changes of environmental protection requirements; many innovations in the design of waste water treatment plants by this firm have followed changes in regulatory requirements.

Up to now, this paper has discussed various sources of designer's technology which are essential suppliers of product innovation in construction. A mediation/adoption process exists between these various external sources and the designer's bank of technology. The mediation process may be the continual effort of a gatekeeper in the firm, a designer's reading of journals, or informal or formal communication process. Whatever the form of this mediation process, the management of this process is significant for the process of product innovation.

Mediation Process

As an answer to the question regarding the sources of the initial idea for innovation, many designers point out professional journals and informal communications with experienced contractors. Also, they are inclined to be conservative in this adoption process. Popular axioms spread in the manufacturing industries regarding how to get product innovations like "do it, fix it, try it," or "ready, fire, aim" (Peters and Waterman 1982), and other action-biased strategies do not seem to apply in construction. An axiom suitable for the designers seems to be "safety, safety, and safety." In sum, there

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are economical, safety, reputational, and competitive considerations in this adoption process. Adoption of particular technology by a designer or a design firm is thought to be an increasing function of the proportion of designers or design firms already using this new technology, and of the profitability of doing so, but a decreasing function of the size of the investment required, and of the amount of safety risk.

Characteristics of Designer's Technology

The single most important characteristic of designer's technology is that it is not static in nature: Technologies sometimes fade from memory or spawn other unexpected technologies by being matched with existing technology or designer's creativity. This bank of technology of a design firm is also fragmented in nature: Someone may have knowledge about soil mechanics, while another has a background in the technology of computer analysis. An individual designer's bank of technology is similarly fragmented. These fragmented pieces of technology are being circulated, collided, and combined with each other. Thus, the rate and scope of innovation depend on how to manage these characteristics of designer's technology. This topic will be discussed later in this paper.

Contractor's Process Technology

The state of construction process technology affects the design process in various ways. However, the separation of design and production functions is a fact in much of the U.S. AE&C industry. The designer is usually selected by the owner on the basis of his professional reputation; designers are usually forbidden by their associations to engage in price competition for their services. The actual production of a construction project is performed by a general contractor, who is often selected through price competition. Once the project is awarded to a contractor on a fixed-price basis, his major incentives are to increase the profit by decreasing project cost; there is little incentive to improve the quality of the product. The two entities are living in two different worlds: the designer's world of reputation and the contractor's world of price competition and cost reduction. This irreconcilability of goals leads to a lack of cooperation between the designer and the producer.

It is evident that new ideas in design can often be introduced only with or from new materials or methods of production. The construction process technology is one of the forces that motivate or restrict the designer in product innovation. Consequently, cooperation between the designer and the contractor in approaching a project in an integrated manner increases the chance of product innovation.

The first segmental bridge in the United States is a good example in this regard: The contractor initiated the innovation process. The low bidder of a conventionally designed bridge project was a contractor who was associated with a German construction firm that was one of the pioneers in segmental bridge construction. Obtaining the award, the contractor submitted a value engineering proposal that, in essence, described segmental bridge construction method. He got an approval, and by virtue of having experience with this type of construction, he produced savings for both himself and the owner. Also, the final bridge design was stronger than the first.

Implications and Practical Applications

The model of product innovation in construction just described leads to several implications for industry professionals seeking to increase product innovation and researchers trying to better understand this complex process. If the description above is valid, we would expect to find evidence of the following implications on projects that resulted in product innovations. Managers of design firms attempting to increase product innovation would take the actions next indicated to bring about product innovation.

A Living Model

An important implication in this model is that each actor is dynamic. It has a particular characteristic at a certain time. It is affected by surroundings and by purposeful input, and it influences neighbors either positively or negatively. Therefore, the major implication of this model is that the innovation process in construction can be managed by changing certain actors' surroundings and by giving input to certain actors.

More Owners' Demands for Innovation

Owners' demands are the "market pull"–type forces for product innovation in construction. This demand-side factor is dynamic but cautious in nature. However, one positive aspect of this factor is that these demands can be induced by the design firm's good reputation. In fact, the designer's technological competence in handling owner's needs may help the owner shape his or her demands.

This importance and unique nature of owners' demands implies that innovative design firms are also good at building and marketing their reputations as well as in maintaining technological competence. Managers pursuing increased innovation will therefore take purposeful actions to establish a balance between marketing and engineering as a basic strategy and means for innovation.

More Owner Involvement

The owners' indispensable roles in the process of product innovation in construction have already been mentioned. The strikingly important roles of the owners, compared to the users in the manufacturing industry, are that they are the initiators of the process as well as the decisive power holders throughout the project execution. They are major "participants" rather than just "buyers" of constructed products.

Hence, the implication is that the more owner participation in technical matters, and proportionally more risk sharing, the greater the number of product innovations. The owner's active participation during project execution is important for his or her understanding of technical matters and for timely approval of innovative ideas. The risk of failure is a great concern in the AE&C industry. A small failure may bring an undreamed-of disaster, harsh legal and social punishment, and sudden ruin of reputations for both the company and the engineer involved. Thus, it is important for managers to provide the designers/engineers with a way to alleviate the burden of risk by increasing the degree of participation of the owner in the project.

Management of Fragmented Technology

The bank of technology of a design firm consists of various pieces of technology that are dynamic but fragmented in nature. Thus, there are im-

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portant implications in managing this designer's technology. In innovative design firms, these various kinds of designer's technology should be blended effectively, updated continuously, and should spawn other hybrid technologies internally. Managers seeking innovation provide a culture and a system in which these fragmented pieces of technology are rapidly circulated and collided. They consciously pool various technologies together in the form of task forces, trouble-shooting teams, project teams, and other types of temporary organizations.

Management of Mediation Process

Various sources of the designer's technology necessitate an effective mediation/adoption process between external sources and the designer's bank of technology. This description implies that innovative design firms are good in management of this process and have evidence to prove this. This evidence may include a well organized and maintained library, frequent informal discussions with contractors and material suppliers, support for conference attendance, training sessions, frequent visits to construction sites, and others. Designers attempting to increase innovation would have systematized routes and methods to acquire new technology.

Inventing Problems

Problems steer designers toward technological challenges and eventually to product innovation. If problems presented by the project are unique and the designers are challenged, they will be further motivated to explore product innovations. In applying this implication, designers seeking to improve innovativeness will recognize and reorganize problems that would not be problems for others.

Importance of Technology

A linear conceptualization of the innovation process—namely, the view that problems come first, then solving next—may obscure reality in construction and create misleading implications for industry professionals. Designers and engineers may blame a lack of innovativeness on not having unique problems: They treat technology as responsive rather than initiative. However, technologies, as Rosenberg (1982) asserts, "influence the nature of the problems posed for an innovative solution in the first place."

In most innovative projects, it appears that a certain level of solutions precede the problems. That is to say that problems are identified, categorized, and organized in the context of the designer's applicable accumulated technology. Thus the implication of the previous statement is the very importance of a sort of continuous R&D effort—even though not institutionalized, nor in the same fashion as R&D in manufacturing—on a similar product line.

The Importance of Technically Competent Leadership

Many design/engineering firms recognize the importance of product innovation in building and maintaining their reputations; their brochures contain terms like "innovative" and "innovation." Despite this clear recognition of the role of innovation for the success of the business, many managers, especially high level managers, of design/engineering firms tend to have differing conceptions concerning their roles in the innovation process. They no longer see themselves as engineers who actively make design decisions; they claim that their roles as managers prevent them from being personally involved in engineering. The belief in the supremacy of management (including marketing, customer service, management of R&D, etc.) over engineering appears pervasive in design and construction. For example, the top management of design/engineering firms that use proven technology may not personally read professional journals; they have their designers read.

The vital need for management to allocate resources effectively for the successful process of product innovation in AE&C is clear. It is the managers' role to oversee the mediation process and have various kinds of intrafirm technology blended effectively, updated continuously, and used to spawn other hybrid technology internally. However, exclusively focusing on these duties may lead to ignoring the peculiar demands of designing for construction. Failure may only mean losing profits in manufacturing; but in construction, failure often means getting out of business. The risk of failure is higher in construction; the trial-and-error approach is not acceptable. Consequently, managers need a higher understanding of all technologies employed. While their good management practice is a supplementary condition, their technical competence is a necessary provision for the successful process of product innovation in construction.

The implication is that managers from whom the key designers involved in product innovations seek final authority regarding the use of the key ideas need to be technically competent. The managers who desire to increase the rate of product innovation need first to increase their effort to be the true designers/engineers who can bring up the basic concepts or key ideas for product innovation; they need to devote time to continued learning about technical matters.

More Interaction between Design and Production

The state of construction process technology affects the design process in various ways. Often, new ideas in design can only be introduced with, or from, new materials or methods of production; construction process technology is one of the forces that motivate or restrict the designer in product innovation. But the reality is the separation of design from production under conventional contracting arrangements; thus the designer lacks information concerning the input factors of production. Cooperation between the designer and the contractor in approaching a project in an integrated manner is essential for product innovation. This description implies that, assuming other factors are equal, favorable contractual arrangements lead to more innovations. Interaction and cooperation between the designer and the contractor should be encouraged by the contract and by financial incentives for both parties.

Conclusions

In the AE&C industry many firms have shielded themselves from technological competition; they have enjoyed a false sense of security. The industry suffers from declining productivity, falling profitability, and worsening competitive position in the international market. These difficulties are usual in a highly competitive and mature industry like AE&C in which cost

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minimization rather than new product development is the dominant business strategy.

One possible strategy for firms wanting to escape from these industrywide problems is to focus their resources on developing innovative products (or diversifying into new businesses) instead of on cost-cutting activities for which the benefit is eventually diminishing. Japan, for instance, is leading in designing and constructing new tunnels—soft-ground tunnels; Europeans are superior in developing new bridges.

The U.S. AE&C industry needs product innovation. Firms need to put at least as much effort into the development of new products as into cost-cutting process innovation. The AE&C industry needs a growing awareness of the importance of orienting research and business toward product innovation. However, a misleading perception seems to exist concerning the way to increase the rate of product innovation in AE&C. Many construction researchers have persistently urged increased R&D for the survival of the U.S. AE&C industry, some even suggesting the formation of an industrywide organization to coordinate these efforts. This effort is important, but it is also necessary to consider others that play important roles in the process of product innovation in the AE&C industry. Lack of R&D in the AE&C industry has been the most visible scapegoat, and managers are blamed for seeking immediate returns on their investment.

R&D involves only a portion of two actors, the bank of designer's technology and the contractor's process technology. Improvement in only a single actor appears insufficient. To advocate a portion of the solution, ignoring others, is misdirected. Improving the rate of product innovation in the AE&C industry requires considering the four actors and the relations between them. Entrepreneurs will not respond to the suggestion of greater investment in R&D until other factors are more favorable. Examples of questions that managers and researchers need to answer include how to increase owner participation, especially in terms of risk sharing in construction projects; ways to increase the interaction between design and production functions; and the mechanism of inventing problems.

In this paper, the writers suggest a new direction for the AE&C industry and a new emphasis for construction entrepreneurs—developing new products rather than minimizing cost. The model suggests that construction researchers and professionals who develop new products see the process of product innovation with four actors in mind. A great deal of empirical research dealing with the causes and factors of success and failure in construction innovation is necessary to test and refine the description initiated in this paper.

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