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INNOVATION IN THE CONSTRUCTION INDUSTRY

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ABSTRACT

In this paper, existing innovation models are reviewed. The influence of technology and market-driven schools of thought on the creation and diffusion of innovation is examined. Incremental vs. radical models and autonomous vs. systemic models are considered in the context of the construction industry. The concept of "technology adoption life cycle" is investigated to understand better the acceptance of new technology by key parties. A new model of innovation is proposed. In this model, the transformation process of invention into adoption flows through a cyclical mechanism encompassing six phases: 1) need, 2) creation, 3) invention, 4) innovation, 5) diffusion, and 6) adoption. This model clearly shows the interaction of the three most influential domains: users, changes, and the environment. The model also takes into consideration the influence of technology and market-driven forces on the creation and diffusion of innovation. As a consequence of their particular function in the construction activity, construction management firms should perform as catalysts in the generation and diffusion of technological advances in the construction industry.

Keywords: Innovation, invention, innovation models, technology adoption life cycle, construction management.

INTRODUCTION

The issues associated with the creation of an innovative mindset and the flow of innovation among key parties in the construction industry have attracted considerable attention in the literature [1,2,3]. These studies reveal that the mindset of innovation in the construction business is very conservative.

The U.S. construction market has enjoyed a strong and steady expansion in the last few years. This trend is expected to continue through the next decade. But this phenomenon may simply be an overall market maturity, which provides steady work, but not steady growth [4]. In other words, the industry has passed from a period of rapid growth to a period of modest growth. Maturity implies characteristics such as intensified competition for market share, and *incremental innovation* in product and production processes [5].

The goal of this paper is to increase understanding of the importance of innovation and the creation of an innovation mindset in the construction business. Presently, there are common misconceptions concerning the value of an innovative company strategy. Some people in the construction industry interpret the push for innovation as management propaganda or as a marketing gimmick whilst others regard innovation as a "find it-fix it" dynamic. It is difficult to understand the mindset of innovation in the construction industry because of this wide variation of interpretation. This paper explores construction management's role in the process of construction innovation. It briefly reviews several industry models. The adoption of technological innovation, the role of each party in bringing about change, and other issues related to the creation and diffusion of innovation in the construction industry are investigated. An attempt is made to develop a model that can graphically represent the dynamics of innovation in the context of the construction industry.

OVERVIEW OF INNOVATION

Rosenberg [6] theorizes that the nature of a problem will influence an innovative solution. On the other hand, Nam and Tatum [7] claim that some construction professionals tend to act on the principle that they can investigate solutions only after problems are encountered

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and that it is this very attitude, which contributes to the opinion that the construction sector has a conservative nature. However, a substantial body of facts related to real experience should dispel these misconceptions.

Schumpeter's *The Theory of Economic Development* originally published in German in 1911 and in English in 1934, was the first work to make a serious attempt at incorporating innovation into economic theory. It was Schumpeter who first used the word innovation in the sense now used in economics [8]. In the context of construction, innovation can be defined as the first use of a technology within a construction firm [9]. Slaughter [10] argues that innovation is the actual use of a nontrivial change and improvement in process, product, or system that is novel to the institution developing the change. Arditi [11] describes innovation as the translation of knowledge into production that is significantly affected by the level of talent at all stages of a venture. Since innovation is a translation process, this process also entails significant intangible factors associated with time that are related to the complexity within the social and political constraints.

Kuczmarski [12] believes that innovation is not a science, but an art of welcoming risk. Uncertainty, regardless of whether it is *arrovian* (measurable) or *knightian* (immeasurable), means that it is not easy to know whether something will succeed, and this inevitably leads to anxiety. Innovation is not a linear process; it is intuitive at the first step [13]. In terms of organizational psychology, Kuczmarski [12,14] believes that innovation is a mindset and a pervasive attitude, a feeling, an emotional state, an ongoing commitment to newness that requires tremendous change in thinking, or a way of thinking focused beyond the present into the future. Similarly, Bacon and Butler [15] point out that innovation is an action-oriented, practical result, producing a philosophy and process for achieving growth and profits. In the autonomy of the entrepreneurial world, Drucker [16] claims that innovation is organized, systematic, rational work that should be part of any business, and stresses that opportunity is the source of innovation.

Higgins [17,18] proposes four principal dimensions of innovation: product, process, marketing, and management. *Product innovation* is an innovation that produces a qualitatively superior product [19]; this may result in new products or services, or in the enhancement of old products or services [17]. Process innovation results in improved processes within the organization [18]; examples include improvements in construction methods [19], or in the efficiency of standard operations [20]. *Marketing innovation* is the management process responsible for planning future action to identify, anticipate, and satisfy customer requirements profitably [21]; this activity is related to the marketing functions of promotion, pricing, and distribution, as well as to product functions other than product development. *Management innovation* improves the way an organization is managed [18].

THE DYNAMICS OF INNOVATION

The mechanism of innovation takes place in a spectrum with *incremental innovation* at one end, and *seminal/radical/breakthrough innovation* at the other. Gomory [22] defines *incremental innovation* as a cycle paradigm of innovation involving a smooth continuous process, leading to steady improvements in the products or processes. He defines *seminal innovation* as a ladder paradigm of innovation that involves the establishment of totally new products or processes. Freeman [23] goes beyond Gomory's [22] two-tier classification and classifies innovation into three types: Incremental, Radical, and Revolutionary. He differentiates that one type of innovation should exceed incremental and radical innovation, namely, revolutionary innovations that cause significant economic changes. Similarly, Marquis and Myers [24] discern three types of innovation: complex systems involving many elements; radical breakthroughs in technology, which change the character of an industry; and "nuts and bolts" innovations, which occur within the firm.

From the point of view of the firm, Moore [25] claims that the behavior vis-à-vis innovation can be categorized based upon the level of change. He theorizes that *discontinuous innovations* require a change in the current behavior, or a modification in other needed products and services, whereas the contrasting *continuous innovations* refers to the normal upgrading of products not requiring a change in behavior. According to Kline and Rosenberg [26], while some technological changes are in the form of exceedingly visible major innovations, some are less visible and even invisible in numerous cases. Teece [27] theorizes that it is useful to distinguish between two phenomena of innovation: autonomous (or "stand-alone") and systemic.

An *autonomous innovation* is one that can be introduced without modifying other components or items of equipment. The component or device in that sense "stands alone." A *systemic innovation*, on the other hand, requires significant readjustment to other parts of the system. The major distinction between the two relates to the amount of design coordination required for development and commercialization. Hutchins [28] states that even though a system is made up of individual parts, the focus of systemic thinking is the unity, or wholeness of things. The properties of a system are what the parts do as a whole, not what they do separately. In the context of innovation, the system is composed of a complex network of relationships between human, organizational and technical activities, which has the function of producing a need for innovation, which eventually is created, adopted and implemented by the system as a whole for higher performance and competitive advantage.

In the context of the construction industry, Slaughter [10] breaks down the spectrum of innovation into five types: incremental, modular, architectural, system, and radical. *Incremental innovation* is a small change, based upon current knowledge and experience. *Modular innovation* entails a significant change in concepts within a component, but leaves the links to other components and systems unchanged. *Architectural innovation*, on the other hand, involves a small change within a component, but a major change in the links to other components and systems. *System innovation* is identified through the components' integration of multiple independent entities, which must work together to perform new functions, or to improve the facility's performance as a whole. In contrast, a *radical innovation* ("shooting star") is a breakthrough in science or technology that often changes the character and nature of an industry. The main principle of each characteristic is based on the magnitude of change in the state-of-the-art associated with the innovation and the expected linkages to other components and systems. The complexity of these five models in the construction industry can be illustrated by referring to a study where Arditi et al. [29] investigated the number and the technological life of new models of construction equipment introduced every year, and the flow of this innovation into the construction industry. The findings show that the rate of innovation in the construction equipment industry increased during the last 30 years. This increased rate of innovation can be linked to pressures generated by buyers' behavior and to technological developments in the equipment industry as well as in other industries. The findings also indicate that the rate of innovation has been uniform and incremental over these 30 years. Innovations in construction equipment are bound to generate significant benefits for construction companies because the use of advanced models improve their performance and competitiveness. This can possibly change the character and nature of the construction industry.

The Technology Adoption Life Cycle

Smallwood [30] explores a model for understanding the acceptance of new technology, called the Technology Adoption Life Cycle. He studies the product life cycle that goes through introduction, growth, maturity, decline, and termination stages (Figure 1). He demonstrates how the saturation of a product increases in the early stages, reaches a peak in the maturity stage, and declines in the later stages.

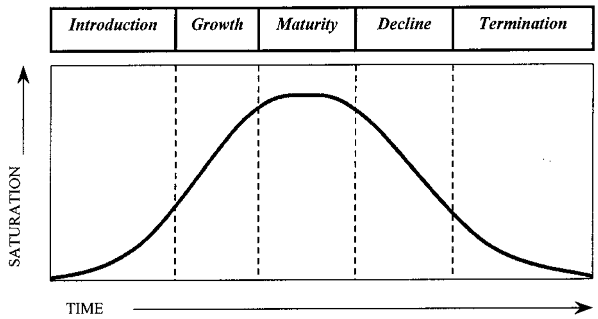

Figure 1. Life Cycle Stages of Various Products [3]

In contrast to Smallwood's [30] Technology Adoption Life Cycle, Rogers [31] and Moore [25] explore the characteristics of this life cycle by considering when technology adoption will take place, and by comparing it with competitors active in the same type of business. While Smallwood [30] is concerned with product behavior, Rogers [31] and Moore [25] concentrate on the adopter's behavior. Rogers [30] and Moore [25] define five types of individuals: innovators, early adopters, early majority, late majority, and laggards. *Innovators* pursue new technology aggressively. *Early adopters* or visionaries, like innovators, buy into new product concepts very early in their life cycle, but unlike innovators, they are not technologists. The *early majority* or pragmatists share some of the early adopter's ability to relate to technology, but ultimately they are driven by a strong sense of practicality. The *late majority* or conservatives share all the concerns of the early majority, plus one major additional one: they are uncomfortable with their ability to handle technology, should they decide to utilize it. As a result, they wait until something has become an established standard before they adopt it. Finally there are the *laggards*. These people simply do not want anything to do with new technology for a variety of reasons, some personal and some economic. Khisty [32] adds *die-hards* to this model so that the life cycle curve becomes symmetric (Figure 2).

Innovators	*Early Adopters*	*Early Majority*	*Late majority*	*Laggards*	*Die-hards*
2.5%	13.5%	34%	34%	13.5%	2.5%

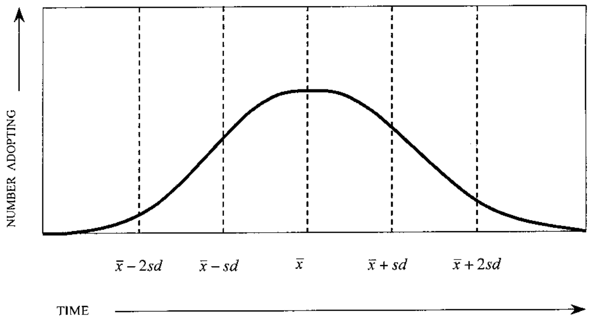

Figure 2. Technology Adoption Life Cycle [25, 31, 32]

Technology-Driven and Market-Driven Innovation

Technology and market drive constitute the continuing debate underlying the motivational forces behind innovation. Technology and market drive are inherently complex phenomena because of their opposite nature. The technology-driven school of thought is rooted in Schumpeter's ideas, and places the major role of innovation creation on technology. In this perspective, new technologies are created through technical knowledge and, if necessary, consumer needs, awareness, and interests are developed along with new products. At the other end of the pole, the market-driven school of thought is derived from Schmookler's [33] work, and suggests that firms perceive profit opportunities in the market and it is with this perspective that technology is developed and adopted. Marketing plays the leadership role and R&D responds with appropriate technologies. According to Ginn [34], R&D may originate the process of innovation and lead it initially, but generally with the concurrence of marketing. Nayak and Ketteringham [35] claim that no breakthrough becomes commercial unless people developing the product see a market niche for it. But it is untrue that the bulk of successful commercial innovation results from market drive rather than technological drive; therefore, this is a reversible analysis.

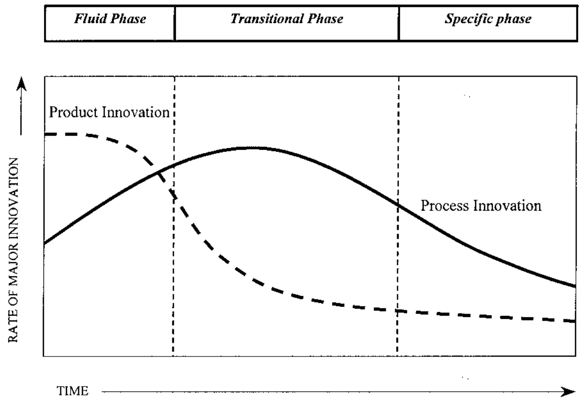

Figure 3. The Dynamics of Innovation [38]

PROPOSED INNOVATION MODEL

A new model named *labyrinth of innovation* is proposed in this paper and encourages its user to rethink the innovation process. The graphical representation presented in Figure 4 describes the flow of innovation so that the engineer, manager, and construction owner can easily understand it.

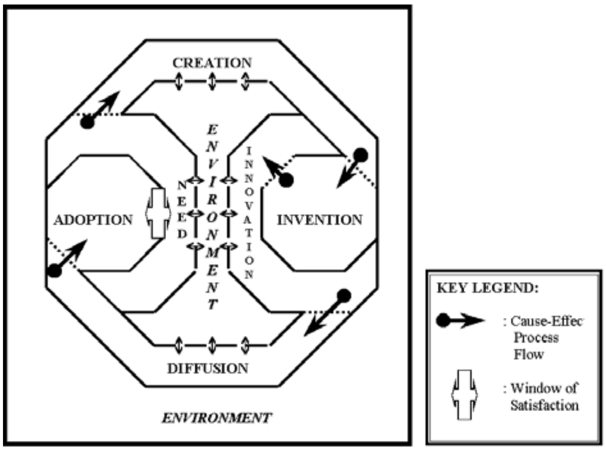

Figure 4. The Labyrinth of Innovation Showing Six Phases: 1) Need, 2) Creation, 3) Invention, 4) Innovation, 5) Diffusion, and 6) Adoption

The parties involved in the construction activity may want to avoid innovation because of the conservative mindset inherent in the construction industry. But they may change their mind if they are able to refer to the proposed model and understand the phenomenon of innovation. The development of the labyrinth of innovation is based upon the flow of successful innovation through six phases: 1) need, 2) creation, 3) invention, 4) innovation, 5) diffusion, and 6) adoption. All of these phases are critical and cannot stand alone. If the process fails during one of these six phases, successful innovation cannot be achieved.

Tabel 1. Strengths and Weaknesses of All Key Parties Invoved in Adopting Innovation

KEY PARTIES	STRENGTHS	WEAKNESSES
OWNERS	• Own capital. • The prime beneficiary from successful innovation.	• Usually no experience and less knowledge.
GENERAL CONTRACTORS	• In charge of all construction activities. • Knowledgeable about all aspects of construction.	• Labor restrictions. • Capital intensive. • Complex legal responsibilities. • The loser in case of failure.
CONSTRUCTION MANAGEMENT FIRMS	• Close to the owner who has capital. • Knowledgeable and experienced. • The beneficiary from successful innovation.	
ARCHITECT/ ENGINEER DESIGNER	• The beneficiary from successful innovation. • Better design for adopting new product innovation.	• Not close to the owner compared to CM firms.
SUBCONTRACTORS	• Expertise in a particular specialty.	• Labor union. • Capital intensive. • Complex legal responsibilities. • The primary loser in case of failure.
SUPPLIERS	• Relationship with general contractors, construction management firms, and subcontractors. • Well-connected to manufacturers	• No relationship with the owner.
MANUFACTURERS	• Provides R & D. • Offers new products.	• No relationship with the owner.

The labyrinth of innovation shows a transformation process, from *invention* to *adoption*. This model was created to satisfy the needs of engineers, managers or construction owners who interact with each other during the creation and diffusion of innovation. Insofar as the user of this model may be involved at any one of the six phases, the model has a cyclical format and continuous process flow. Within this process, there is significant interaction with the environment especially at the need, creation, innovation, and diffusion phases. The *window of satisfaction* is placed at the adoption phase, stimulated and triggered by need. The *window of satisfaction* will indicate the level of user-delight in bringing newness into the organization. When users are satisfied with a new adoption, their need is fulfilled, but if satisfaction is not achieved, their desires will lead to other needs. This cyclical phenomenon is called *continuous innovation.* Because of the complexity of innovation and myriad aspects of the environment, all influences cannot be considered simultaneously. This model shows that, generally, the dynamics of innovation is such that the phases interact with parts of the environment (inner dumbbell shape) rather than its entirety. The system itself is complex and the participants often lack knowledge, experience, expertise, and, many times, confidence.

Interaction of Different Domains

The labyrinth of innovation shows the interconnection of the three most influential domains in the model: users, changes, and the environment. Figure 5 graphically represents the domain of the environment as a vertical bar between the two domains of users and changes. The environment is like a barrier, which includes legal and financial conflicts, conflicts of intention, and technical approval difficulties. A negative organizational mindset acts as a barrier to bringing about change into the users' domain as well. Because during creation and diffusion participants have direct contact with the environment, attributes of the environment are considered in these two phases. Diffusion serves as a bridge, bringing change to the domain of users, while the users generate creative thinking – through the need for better innovation – thus bridging back to the domain of change.

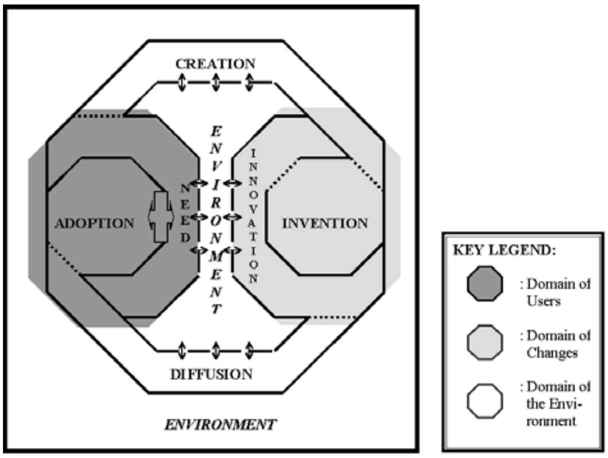

Figure 5. Interaction of Different Domains in the Labyrinth of Innovation

Motivational Forces

Figure 6 clearly shows the spectrum of market-driven and technology-driven innovation at the two extremes. The interaction occurs especially during the processes of creation and diffusion. In the creation phase, there are two influences: *market-push* and *technology-pull. Market-push* is characterized by the market demand for new technology, while *technology-pull* is characterized by how technology creates the need for new technology. In the diffusion phase, *market-pull* and *technology-push* are again the two influences. *Market-pull* is characterized by how the market stimulates the diffusion of new technology, while *technology-push* is characterized by how new R&D triggers diffusion among firms. While technology-push is critical in the invention phase, market-pull plays a greater role in the adoption phase.

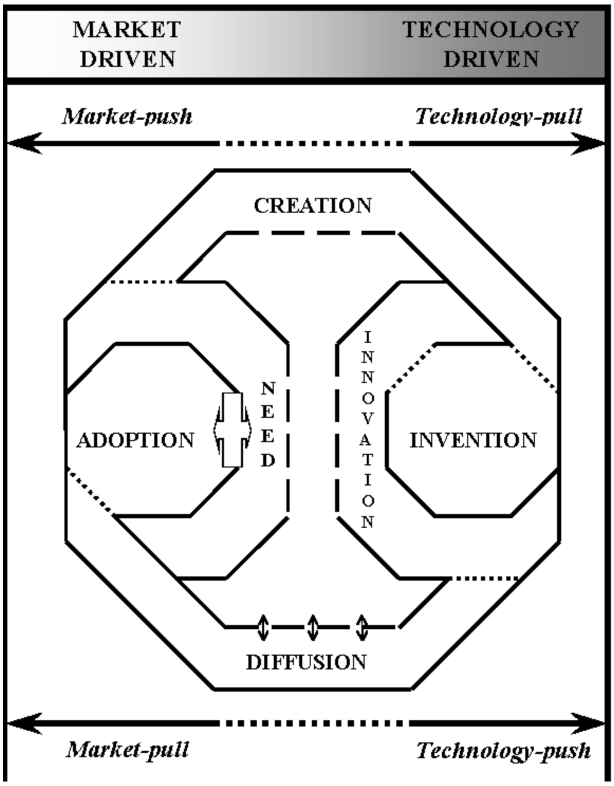

Figure 6. Motivating Forces in the Labyrinth of Innovation

THE FLOW OF CONSTRUCTION INNOVATION AMONG KEY PARTIES

Von Hippel [36] points out that the user is the innovator, so the value of innovation should focus on consumer delight, which is no easy task since consumers are becoming increasingly more demanding. In terms of builder-manufacturer interaction, Slaughter's study [1] indicates that builders create almost all of the identified innovations in the construction industry. She states that builders, more willingly than manufacturers of components and materials, are often the sources of innovation. Builders have not only created the majority of innovations, but they have also created significantly different innovations than manufacturers; builders' innovations explicitly integrate disparate components into a functioning whole unit.

Project and Product-Oriented Knowledge

Although Slaughter [1] claims that builders are the innovators, builders generally do not have an R&D department. These two arguments seem inconsistent. It can be argued that both arguments are right, and that construction innovation is based upon two different frameworks.

In the context of a service industry, the product-oriented and project-oriented motives of the key parties play a significant role in the generation of technological advancement within the organization. In favor of a balance within the system, mutual orientations must be considered and there is no assumption that one framework is more competent than the other (Figure 7).

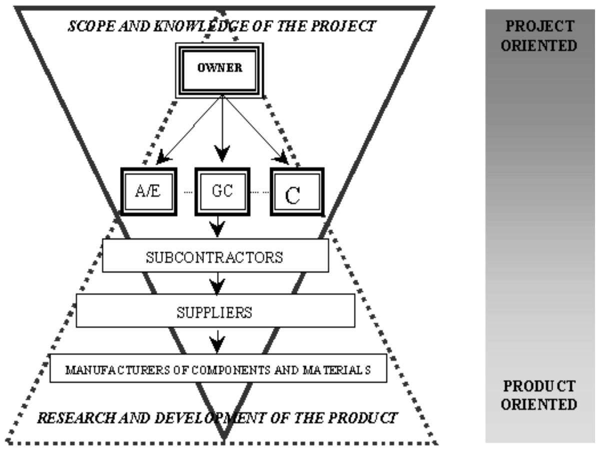

Figure 7. Project and Product Knowledge Pyramids Among Key Parties in the Construction Business

CONCLUSION

The development of new innovation models has recently emerged as a challenging topic. Research associated with the definition, nature, function, and modeling of innovation has been conducted by Schumpeter [37], Smallwood [30], Rogers [31], Tatum [2], Von Hippel [36], Higgins [18], Utterback [38], Kuczmarski [39], and Slaughter [10], to name but a few researchers. Numerous studies have illustrated how an innovation mindset varies significantly under the technology-driven and market-driven schools of thought. The dynamics of innovation are based upon a wide spectrum of possibilities within the system, including incremental innovation at one extreme and breakthrough innovation at the other. Innovation is a process where the learning experience and technology adoption life cycle contribute to the creative thinking behind underlying motivational forces, whether technology or market-driven. A better understanding of the creation and diffusion of innovation is achieved by considering various perspectives of innovation such as incremental-radical, continuous-discontinuous, autonomous-systemic, and innovator behavior models, as well as studying the technology adoption life cycle defined by Rogers [31], Moore [25], Smallwood [30] and Utterback [38]. This study attempts to rethink the dynamics of innovation in the construction industry.

The proposed symmetrical model shows how the innovation process can flow through a cyclical mechanism that encompasses six phases of need, creation, invention, innovation, diffusion and adoption. This new model represents the entire phenomenon as a transformation of need into adoption of novelties. There is significant interaction with the environment especially at the need, creation, innovation, and diffusion phases. The environment, which acts as a barrier, presents financial, legal, conflict of interest and attitude challenges. Much effort must be spent towards environmental considerations to achieve successful innovation and fulfill user need. The model also shows that technology- and market-driven forces are at opposite poles, influencing the process of innovation equally. Market-push and technology-pull are the motivating influences in the creation and diffusion phases.

Several construction industry researchers have claimed that the builder is the innovator. In the crux of a service industry, product-oriented and project-oriented motives of the key parties play a significant role in the adoption of innovation. The characteristics of construction management firms indicate that construction management firms perform as catalysts in the generation of technological advances.

Construction innovation occurs incrementally over a period of many years, and as a consequence, is often invisible. Regardless of its conservative reputation, the construction industry does innovate and adopt technological change, nonetheless slowly.

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