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Prevention through Design Adoption Readiness Model (PtD ARM): An integrated conceptual model

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Abstract.
BACKGROUND: Prevention through Design (PtD), eliminating hazards at the design-stage of tools and systems, is the optimal method of mitigating occupational health and safety risks. A recent National Institute of Safety and Health initiative has established a goal to increase adoption of PtD innovation in industry. The construction industry has traditionally lagged behind other sectors in the adoption of innovation, in general; and of safety and health prevention innovation, in particular. Therefore, as a first step toward improving adoption trends in this sector, a conceptual model was developed to describe the parameters and causal relationships that influence and predict construction stakeholder "adoption readiness" for PtD technology innovation.
METHODS: This model was built upon three well-established theoretical frameworks: the Health Belief Model, the Diffusion of Innovation Model, and the Technology Acceptance Model. Earp and Ennett's model development methodology was employed to build a depiction of the key constructs and directionality and magnitude of relationships among them. Key constructs were identified from the literature associated with the three theoretical frameworks, with special emphasis given to studies related to construction or OHS technology adoption.
RESULTS: A conceptual model is presented. Recommendations for future research are described and include confirmatory structural equation modeling of model parameters and relationships, additional descriptive investigation of barriers to adoption in some trade sectors, and design and evaluation of an intervention strategy.

Keywords: Prevention through Design (PtD), technology adoption, construction, engineering controls

1. Background

1.1. Prevention through Design (PtD)

1.1.1. History

The optimal method of preventing occupational illnesses, injuries, and fatalities is to "design out" the hazards and risks; thereby, eliminating the need to control them during work operations. This approach involves the design of tools, equipment, systems, work

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processes, and facilities in order to reduce, or eliminate, hazards associated with work. Prevention through Design (PtD) has been defined by Schulte et al. (2008) as:

> *The practice of anticipating and "designing out" potential occupational safety and health hazards and risks associated with new processes, structures, equipment, or tools, and organizing work, such that it takes into consideration the construction, maintenance, decommissioning, and disposal/recycling of waste material, and recognizing the business and social benefits of doing so* [1].

The PtD movement saw its genesis in the early 1990's, with the formation of a committee within the National Safety Council (NSC) to study the feasibility of incorporating safety reduction into design procedures. The outcome of this early work was the formation, in 1995, of The Institute for Safety through Design, with membership from industry, academe, organized labor, and other interested parties [2]. Seminars, workshops, and symposia were held throughout the late 1990's and early 2000's. In 2006, the Australian government issued a guideline on the *Principles for Safe Design for Work*, and in 2007 a special edition of *Safety Science* was published on "Safety by Design". Also in 2007, the OSHA Construction Alliance Roundtable Design for Construction Safety Group developed a short course entitled, "Design for Construction Safety" and the Institute of Mechanical Engineers held a workshop entitled, "Risk Education for Engineers" [2]. One of the goals of the latter was to advance the understanding of the importance of educating undergraduate engineers in risk assessment techniques.

In 2008, the National Institute for Occupational Safety and Health (NIOSH) launched a national PtD initiative; calling on all major industrial sectors to emphasize hazard mitigation at the design stage of tools, facilities, and work processes [1]. NIOSH partnered with the American Industrial Hygiene Association (AIHA), the American Society of Safety Engineers (ASSE), the Center to Protect Workers' Rights, Kaiser Permanente, Liberty Mutual, the National Safety Council (NSC), the Occupational Safety and Health Administration (OSHA), ORC Worldwide, and the Regenstrief Center for Healthcare Engineering, in the development of a *National Initiative on Prevention through Design*, launched in a 2007 workshop and published in a special edition of the Journal of Safety Research in 2008 [3].

One conclusion of the 2007 workshop was that there are two major gaps to be addressed, in order to advance the implementation of PtD in industry. The first is that design professionals such as engineers, industrial designers, and architects, need to consider health and safety implications of end-use of their designs. The second is that business decision makers, including those who purchase products and services, will need to establish a demand for such PtD designs. The PtD Initiative aims to focus "both on the supply of innovative design solutions and on creating a demand among business decisions makers who will value and request them" [1]. Therefore, the work described in this paper aims to address these gaps through advancement of our understanding of factors underlying and influencing PtD supply and demand and through development of a model to predict "adoption readiness" among key construction stakeholders: the workers and owners of small and large firms. The work described herein, the development of a PtD Adoption Readiness Model (PtD ARM), is part of a larger research initiative in which model-based intervention strategies are being developed and evaluated. The intervention strategies will initially target PtD within the drywall finishing trade; however, the model has been developed within the context of the larger construction industry. Future research will be directed at expanding the PtD Adoption Readiness intervention strategies into other high-risk construction sectors: masonry, asphalt roofing, and welding trades.

1.1.2. PtD in the construction sector

PtD to reduce construction occupational risk has received attention in the scholarly literature since the early 1990's. A pivotal article by Hinze and Wiegand (1992) found that only one third of design firms factored construction worker safety into the design process [4]. Predominant hazards addressed by those firms factoring safety into design were excavation/trenching and fall risks. Concerns over liability were identified as a major barrier to diffusion in the design community. The Construction Industry Institute conducted a study in the 1990's to assess and enumerate construction "best practices" for PtD. This study led to the development of a tool entitled "Design for Construction Safety ToolBox" [5].

The United States is said to lag behind other developed countries in the diffusion of PtD innovation and adoption of PtD approaches within construction [6]. These concepts have been widely accepted throughout the European Union and Australia. Barriers to the diffusion of PtD had been encountered by these countries

and lessons can be learned from their experiences. Toole (2005) makes the case that liability concerns may be a larger barrier to PtD adoption in the U.S., due to the litigious nature of the business climate in that country [7].

Much of the literature on PtD in construction has focused on one definition of "design": the activities which are performed by architects and engineers engaged in designing the facility (building or infrastructure component) to be constructed. Concerns regarding assumption of liability are most prominent when this aspect of design is what is being considered, because these designers are but one of the many stakeholder groups engaged in risk management throughout the construction life cycle and may be reluctant to assume risk for all stakeholder groups. However, PtD has a broader definition and applies to the design of all tools, equipment, materials, and work processes that are employed during the construction process; as well as to the design of the constructed environment itself. Therefore, hazard reduction can be accomplished via a multitude of means; such as, changes in tool selection, material composition, work process management, or facility design. This article emphasizes design of tools, equipment, and materials that are employed during construction operations; rather than the design of buildings or infrastructure components. The designs for these tools, equipment, and materials are typically performed by entities that are suppliers to the construction life cycle, but not key players in the actual construction process itself. The onus falling on the construction stakeholder groups is the decision to adopt, or not adopt, the innovative tools, equipment, and materials. Therefore, "adoption readiness" is the endogenous, or predicted, variable of interest in the PtD ARM conceptual model.

1.2. Objective

1.2.1. Prevention through Design examples

The PtD ARM has been developed to address diffusion of PtD innovations for the control of chemical health hazards in construction. PtD approaches to reducing occupational health risk from chemical hazards fall into three major categories: material substitution, isolation, and process re-design. Process re-design approaches can be further divided into three categories: wet methods, local exhaust ventilation systems, and work process changes. Masonry operations, drywall finishing, asphalt roofing, and welding are associated with some of the most pressing occupational health hazard risks in construction. Therefore, these are the construction trades initially targeted by the PtD ARM.

PtD solutions do exist to control the hazards associated with these construction operations; however, many require additional research and development and/or greater diffusion within the industry. PtD designs for the control of particulate hazards in masonry, concrete, and drywall operations include: local-exhaust tool-mounted ventilation, wet methods, isolation, and sweeping compound for clean-up activities [8–11]. Likewise, there are some PtD control options available to reduce the exposure to roofing asphalt fumes and vapors: delivery to the rooftop via tanker rather than kettle and hot lugger system; lidded rooftop containers such as hot luggers, mechanical asphalt spreaders, and felt-laying machines; insulated kettles; insulated hot luggers; fume-suppressing asphalt; and local-exhaust ventilation systems [12]. The main exposing activities are those associated with the asphalt kettle operation and rooftop application. Delivery of the hot asphalt to the job site can be accomplished via a tanker, which would eliminate the on-site kettle operation for handling and heating the asphalt. Roof application exposures can be reduced through the use of lidded and insulated distribution systems. Asphalt fume emissions from the kettle can be reduced by maintaining a constant temperature and preventing the release of fumes. A variety of thermostatically controlled heating systems are available to maintain a set asphalt temperature in the kettle. Kettles are often constructed of double walls with thermal insulation. They may also have double lids to maintain temperature and control exposures. Local exhaust ventilation (LEV) emission capture systems have been introduced for use on kettles to evacuate fumes from the headspace inside the kettle [12]. Automated mechanical systems for rooftop application of mopping layers can be used to remove the human operator. Low-fuming asphalt has been developed to reduce the emission of asphalt fumes from the kettle. A polymer additive to the asphalt separates and forms a floating skim on the surface of the hot asphalt. Initial field studies indicate that the skim dramatically reduces fume emissions [12]. Local exhaust ventilation (LEV) is the engineering control recommended to prevent worker exposure to metal fumes during welding [13]. A material substitution solution is in development for control of welding risks. A low-smoke welding wire has been developed and tested for use in welding as another method of contaminant control [14].

1.2.2. Usage of PtD innovations in construction

Several of the PtD solutions for dust exposures in the masonry or drywall trades are not presently commercially available [15, 16]. Further research and development activities are needed to design and market the following: handheld masonry saws with local-exhaust ventilation, hand-operated surface-finishing grinders with local-exhaust ventilation, water-fed jackhammers, and enclosure systems for stationary masonry saws. Designs which incorporate usability and effectiveness parameters previously identified in the literature are needed [17].

Some of the PtD solutions that are commercially available are not widely adopted in the industry. Ventilated angle grinders for tuck-pointing operations and ventilated drywall sanders are not widely adopted by the industry [15, 16]. Similarly, local-exhaust ventilation emission capture systems for roofing asphalt kettles, automated systems for hot asphalt conveyance, and low-fuming asphalt are all promising PtD strategies for risk reduction in roofing; however, the industry adoption trends and barriers have yet to be described empirically [12]. Lastly, most of the PtD solutions for welding risk mitigation are currently in the early stages of development. The further refinement and marketing of PtD solutions such as the "smokeless welding gun", the low-smoke welding wire, and the local-exhaust ventilation systems for welding are needed.

Because of the low rates of adoption of PtD innovation within the construction industry, the present work sought to develop a conceptual framework that will describe the constructs of importance in enhancing adoption readiness. This framework was based upon previous findings regarding the barriers that are preventing widespread innovation diffusion, as described below.

1.2.3. Barriers to PtD adoption

Much of the research on innovation in the construction industry has focused on the barriers to adoption [18]. Adoption of innovations in construction has been defined as a firm's use of a technological innovation in at least 25% of the cases in which it has an opportunity to use it. (18) Industry barriers to adoption include, market changes, negative perceptions of innovation, and inflexible performance standards. Frequent downturns in the construction market may deter firms from adopting innovations. (19) Regulatory bodies in construction can also have an impact on the successfulness of innovations. The development of new products or processes in construction is not always welcomed by all parties [20]. Building codes and construction regulations often serve as constraints or drivers of innovations [21]. Stringent standards for product performance, safety and environmental impacts can create pressure for firms to innovate, improve quality, and upgrade technologies [22]. Unions may resist innovations that are viewed as labor saving or eliminating products or processes [19].

Cost, risks, uncertainty and limited control over the way construction work is performed and the products that are chosen make diffusion of innovation in the construction industry difficult [19]. Barriers that affect the implementation of innovations also include contract issues, the cost of research, lack of information about available innovation, and lack of awareness of potential cost savings of adoption [23]. Evidence that products and processes will provide an advantage over existing methods and products can serve as a driver for adoption. A study by Toole found that builders become more likely to adopt a product if they have witnessed that product in successful use elsewhere [24]. Builders are frequently unwilling to adopt innovations because of concern over risk and lack of awareness of benefits [21].

One significant barrier to adoption for safety and health innovation in the construction industry is a lack of knowledge of health risks [25]. The lack of understanding that hazards exist or that controls are available can influence the decision to adopt. Managers tend to devote more attention to items that are failing than to those that are meeting their targets [26].

In a study of technology-adoption barriers from the worker perspective, drywall-finishing workers participated in semi-structured, in-depth personal interviews [27]. Attitudes and perceptions toward dust-control technologies were solicited and emergent themes were explored. The HBM served as the framework for understanding workers' readiness to adopt control technology. Workers tended to perceive a risk to health associated with the dust; however, assessments of personal susceptibility to disease were low. Identified barriers to adoption were organizational factors and self-efficacy. The participants expressed little confidence that management would value worker health and reported a perception of having little personal control over the decision to adopt this technology.

In a study of owner perspectives on dust control, a telephone survey was conducted to identify barriers to technology adoption and to explore firm owner perception of risk [28]. Barriers associated with technology usability, productivity, and cost were identified. Additionally, a misperception of the risk to worker health

was interfering with motivation to adopt the PtD innovations.

Research by Koebel [29] has documented the complexity of innovation diffusion in the construction industry. Several industry characteristics are considered impediments to innovation, particularly: site variability, the "one-off" project character of most building construction jobs, regulatory climate, industry fragmentation and decentralization, a low level of research and development (R&D) investment, boom-bust business cycles, and the position of construction companies in the supply chain [29, 30]. Key factors influencing diffusion can vary across firm size, including the role of champions and the information channels influencing diffusion.

Although prescriptive building codes are often perceived as impediments to innovation in construction, governmental regulations can be very instrumental in influencing innovation adoption and diffusion, but the impacts are complicated and sometimes have opposing effects [33]. The traditional model of regulation frequently mandates adoption of specific health and safety practices or adherence to standards of performance. The long history of automotive safety innovations points to the co-evolution of regulatory mandates and safety innovation diffusion [34]. Jensen, Halvorsen and Shonnard [35] found that effective federal energy policies include both incentives and impediments for the adoption of lignocellulosic ethanol as a low carbon fuel source. In the macroeconomic literature on induced innovation, regulations impacting factor prices are expected to induce innovations in response to prices. Jaffe and Palmer [36] found that regulatory compliance costs had the expected positive effect on patenting of environmental technologies by industry. Taylor, Rubin and Hounshell [37] also found that regulatory stringency induced innovation and diffusion of sulfur dioxide control technologies; Kammerer [38] reported similar results for environmental product innovation among appliance manufacturers in Germany. Bossink [39] found that government regulations and incentives were drivers of innovation in construction networks in the Netherlands whereas 'market-pull' from the building owner did not induce construction innovations. The timing, character and composition of regulations, including the mix of mandates and incentives, are likely to be important in the diffusion trajectory of PtD health and safety innovations in the construction industry.

In a study of two national surveys of innovation adoption in the residential construction sector, factors affecting technology adoption by small and large firms were identified. Small builders were found to be more receptive to innovation and the influence of key "technology champions" [31, 32]. Demonstration projects that introduce new technology to owners of small firms were found to convert these builders into champions of the innovations. In large-scale production residential building firms, it was found that technology-adoption decisions were more likely to be made by purchasing units of the organization. Therefore, the technology champion model had less impact in this sector. The study suggested that these larger firms should be targeted with information about affordability, efficiency, and productivity of innovations to increase adoption and diffusion within the large-scale residential construction sector.

1.2.4. Adoption Readiness

Adoption Readiness has been defined as a "state-of-mind about the need for an innovation and the capacity to undertake technology transfer" in a comprehensive review of the literature on the subject [40]. It is the cognitive precursor to "behaviors of support" for the actual transfer effort. Individual and organizational readiness for change are said to involve beliefs, attitudes, and intentions regarding; 1) the extent to which changes are needed, and 2) the level of capacity available to make the requisite changes. Adoption readiness is the first phase in the "natural cycle of change" model advanced by Lewin [41]. Defining readiness for change in this way has two important implications for the design and implementation of technology transfer interventions: readiness can be enhanced, and it can be assessed [42]. Readiness for change is not a fixed element of individuals or systems. It may vary due to changing external or internal circumstances, the type of change being introduced, or the characteristics of potential adopters and change agents. Thus, interventions to enhance readiness are possible and can increase the overall success of technology transfer [43].

2. Methods

2.1. Conceptual model development

Model development was performed according to the five-step methodology for conceptual model development established by Earp and Ennett [44] and advanced by Carpiano and Daley [45], which are:

1. Identify a theoretical framework, or sets of frameworks, that may explain phenomena of interest;

2. Identify important constructs. These are abstract concepts drawn from a theory. Constructs are used to guide the appropriate selection of observed measures or variables.
3. Detail the causal flow, which typically proceeds from left to right. Variables appearing to the left of the model are assumed to be causally antecedent to the variables appearing on the right.
4. Detail causal relationships using arrows
5. Illustrate the direction of hypothesized causal relationships.

2.2. *Identification of theoretical frameworks (Step 1)*

Because the research described in this paper seeks to address a problem of adoption and diffusion of technology that is designed to improve health outcomes, well-established theoretical frameworks were chosen from the fields of health promotion, technology adoption, and innovation diffusion. These theoretical frameworks are highly interrelated and address from their own perspectives very similar outcomes: the decision to use new practices or products. A framework integrating these theoretical models was needed to describe constructs that are pertinent to decision-making that is related to both health behavior and to technology adoption. the PtD ARM was developed to describe this health behavior scenario that involves technological innovation.

2.2.1. *Health Belief Model*

The HBM was developed in effort to predict health-related attitudes and behaviors and has been applied to study all types of health behavior. The HBM has been used to explain both adoption (compliance) and maintenance (adherence) of behavior change. It has been employed in various configurations of the original model developed by social psychologists in the U.S. Public Health Service in the 1950's. [46, 47] The original HBM contained the following four key constructs:

1. Perceived susceptibility: an individual's assessment of their risk of getting the condition
2. Perceived severity: an individual's assessment of the seriousness of the condition and its potential consequences
3. Perceived barriers: an individual's assessment of the influences that interfere with or discourage adoption of the promoted behavior
4. Perceived benefits: an individual's assessment of the positive consequences of adopting the behavior

Subsequent to the Rosenstock version of the HBM, other authors added modifying factor constructs, which have been found to influence the perceptions described above. These are: demographic variables, socio-psychological variables, perceived self-efficacy, cues to action, health motivation, and perceived control.

2.2.2. *Technology Acceptance Model*

The Technology Acceptance Model (TAM) was developed by Davis [48] to explain the factors that influence the decisions to accept or use new technology [49]. The TAM was originally designed to understand and predict user intentions to accept new computer technologies but has been used to understand technology acceptance in various fields of study including medical technology, communication systems, and information technology [50–54]. The TAM has been used to show that prospective adopters' behavioral intentions to use a technology correlate to the actual usage of the technology [50]. If potential users do not fully accept the new technology, they can obstruct the new system and cause it to be underutilized [53]. The TAM is comprised of two main constructs: perceived usefulness (PU) and perceived ease of use (PEOU) [48].

PU has been found to have a strong influence on perceptions of new technology [50]. Davis [48] further described perceived usefulness by showing six ways potential adopters judge the usefulness of a technology which include: (1) does the technology allow the adopter to do the job more quickly? (2) Does using the technology improve the user's job performance? (3) Does using the technology increase productivity? (4) Does using the technology increase the effectiveness of the user's job? (5) Does using the technology make it easier for the user to do the job? (6) Does the user find the technology useful?

PU can have short-term implications to a user, such as improving job performance. It can also have long-term implications to a user, such as improving the user's status in the company over time or improving the user's health [50]. Potential adopters form usefulness judgments by comparing what the new technology is capable of doing and what they need to get done to fulfill the requirements of their job. There are similarities between the PU construct of the TAM and the relative advantage construct in Rogers' diffusion of innovation model [50]. An emphasis on PU and relative advantage will help

in the design of effective interventions that promote acceptance of new technology [49].

PEOU can also have a strong influence on acceptance of new technology. The perception that a technology is easy to use will have a direct effect on its acceptance, since technology viewed as being easy to use is more likely to be accepted [48]. If a technology is viewed as easy to use, then the perceived level of usefulness has also been found to increase [51, 53]. PEOU has been shown to have a smaller, but still significant, effect on user intentions to accept technology. This effect decreases over time, due to gains in self-efficacy with increased usage [50]. PEOU is analogous to the construct of complexity from the diffusion of innovation model [54]. The HBM construct of self-efficacy has also been compared to ease of use [52, 54]. The influence of PEOU is greater in organizational settings where adoption is mandatory; while, in voluntary settings, PU is the stronger determinant of intention to use technology [53].

2.2.3. Diffusion of Innovation Model

Rogers' Diffusion of Innovation is a model that describes diffusion as "the process by which an innovation is communicated through certain channels, over time, among the members of a social system "[55]. Rogers theorized that innovations would spread through society in a normal distribution and that market saturation would be described by a logistic function. Early adopters select the technology first, followed by the majority, until a technology or innovation is used commonly. The Rogers model is essentially a process of incremental learning and transfer of knowledge from the initial set of users (adopters) to potential users. Innovation is defined as a significant improvement in a product, process or system that is new to those who will be developing or using it [56]. One of the necessary components of an innovation is the ability of the innovation to improve some aspect of the adopter's performance of a work task (relative advantage) [24].

Much diffusion research has focused on the conditions that increase or decrease the likelihood that a new idea, product, or practice will be adopted by members of a given culture. The mechanism of diffusion is described as a five-step learning process: knowledge, persuasion, decision, implementation, and confirmation. In the knowledge stage, the person becomes aware of an innovation and has some idea of how it functions. In the persuasion stage, a favorable or unfavorable attitude toward the innovation is formed. In the decision phase, the person engages in activities that lead to a choice to adopt or reject the innovation. If the choice to adopt is made, then the implementation phase follows; in which, the person puts the innovation to use. The final stage is described as confirmation, wherein the user evaluates the results of the innovation.

Diffusion relies on the communication of information about the characteristics of innovations to potential adopters via a variety of networks. The logistic function reflects the bandwagon contagion effects of increased adoption. The earlier stages of diffusion, launch and early adoption, are more critical in establishing the overall trajectory of the diffusion curve. Many of the PtD innovations reviewed in this article are currently at the critical "launch" or "early adoption" stages of the diffusion cycle. The learning that occurs at these initial stages heavily influences the ultimate scale of the diffusion curve. Planned intervention, designed to increase adoption readiness at these early stages can enhance the overall diffusion trajectory and impact of the PtD on the construction industry.

2.3. Identification of constructs (Step 2)

2.3.1. Overview

Constructs selected for inclusion in the integrated conceptual model are summarized in Table 1, and the rationale for their selection is provided in the sections that follow.

2.3.2. Health Belief Model constructs

Perceived susceptibility, perceived severity, perceived benefits, perceived barriers, and self-efficacy are all factors influencing the decisions people make to adopt behaviors that will lead to improved health outcomes [57]. Based on the findings of the Young-Corbett studies [27, 28], described earlier in the Barriers section, the following constructs were selected for inclusion in the model: perceived disease susceptibility, perceived disease severity, self-efficacy, trust in technology, and trust in organization. These studies identified both worker and owner perceptions. Workers reported low personal susceptibility and that self-efficacy and organizational trust were considered barriers to adoption. Owners identified trust in technology factors and low perception of health risk as barriers to adoption.

2.3.3. TAM constructs

PU is defined as the degree a person believes that using the a new technology will increase their effectiveness or performance while PEOU is defined by the potential adopter's view of how much effort will be

Table 1
Identified model constructs

Construct	Stakeholder group	Description	Theoretical framework
Perceived Risk to Worker Health	Workers and Owners of Firms (large and small)	Worker perception of susceptibility to dust-related illness and large firm owner perception of risk to worker health	HBM
Self-Efficacy	Workers	Workers identified a perceived lack of individual control over the decision to adopt dust control technology	HBM
Perceived Susceptibility	Workers	Worker perception of personal likelihood of becoming ill	HBM
Perceived Severity	Workers	Worker perception of potential severity of health outcomes	HBM
Perceived Ease of Use	All	Perception of how easy or difficult to to use the new technology will be	TAM
Perceived Usefulness	All	Perception of the benefits associated with adoption	TAM
Trust in Organization	Workers	Workers identified a lack of trust in organization to protect their health	TAM
Trust in Technology	Workers	Trust in Technology has been found to impact technology acceptance	TAM
Relative Advantage	Firm Owners and Purchasing Agents	Perception of how innovation will impact productivity and quality	DOI
Relative Advantage	Firm Owners and Purchasing Agents	Perception of how reliably the technology will perform.	DOI
Reliability	All	Perception of benefits to be attained through adoption	All
Perceived Benefits			

required to adopt the new technology [48, 49]. These two constructs of the TAM have been shown to be strong determinants of predicting adopter intentions to accept technology [49]. Trust in technology has also been associated with the TAM and has been found to have a direct influence on a behavioral intentions to use a technology and has a positive effect on the PU and PEOU constructs of the TAM [58]. If a technology is perceived as useful, then trust in that technology is increased [59]. Therefore, PU and PEOU are selected for inclusion in the integrated conceptual model. Additionally, the model depicts anticipated relationships between these and modifying constructs, such as: trialability, complexity, observability, compatibility, trust, relative advantage, and reliability.

2.3.4. DOI constructs

The characteristics of innovation that are that are responsible for influencing the rate of adoption are: relative advantage, compatibility, complexity (ease of use), triability, and observability. Increasing perceived relative advantage, compatibility, triability and observability; while decreasing the perceived complexity, will result in increased adoption [60]. According to Rodgers, 49–87 percent of the variance in adoption rate is explained by these characteristics [55, 61]. Innovative individuals in social systems, known as opinion leaders or innovation champions, can influence the diffusion of innovation [62, 59, 55]. Preventative innovations have been perceived as having low relative advantage, when compared to other innovations that are designed to create a profit [60]. Perceived relative advantage has been found to be the most important predictor of the rate of diffusion for preventative innovation adoption [55]. Therefore, the constructs selected for inclusion in the integrated conceptual model are: perceived relative advantage of using the PtD technology, with regard to production capability and quality.

2.4. Detail of causal flow and relationships (steps 3 – 5)

Incorporated in the conceptual model are arrows indicating the major direction of influence of constructs on one another. Arrows point to constructs that are being influenced. Anticipated correlation magnitude is also indicated in the model, through plus and minus signs placed along the arrow lines, to indicate the nature of the anticipated relationship. For correlations that are anticipated to be positive or negative, + or – signs are used,

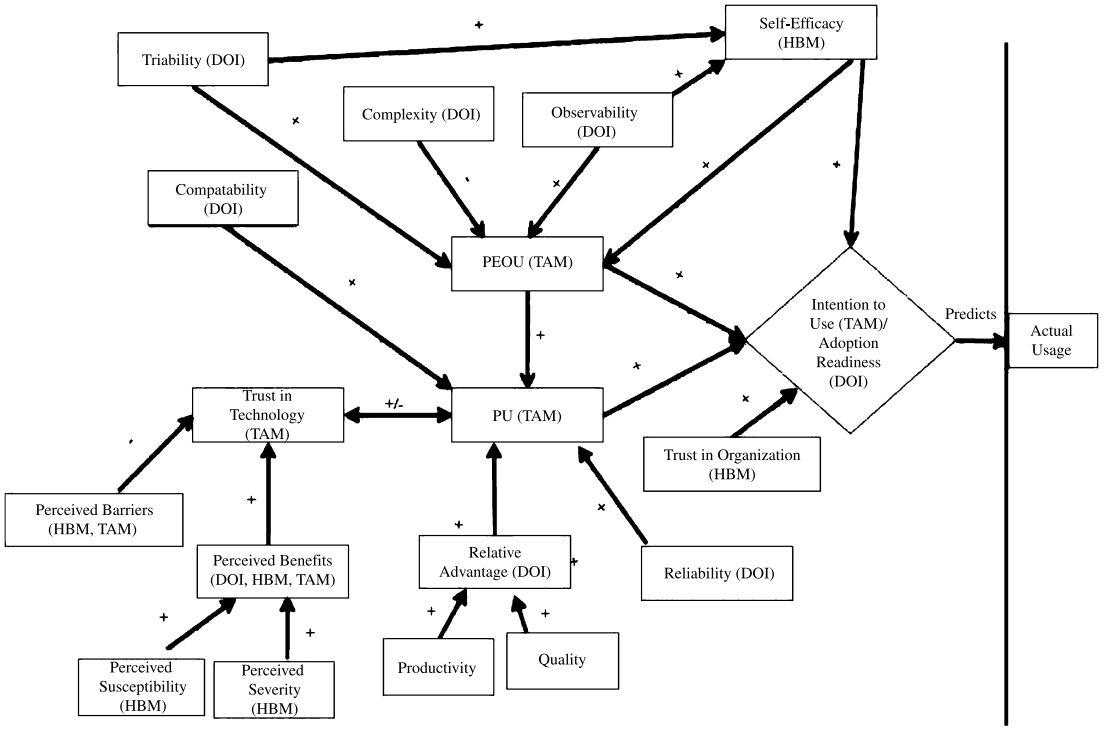

Fig. 1. PtD Adoption Readiness Model (PtD ARM).

respectively. For relationships between antecedent and predicted variables that are more complex, the ± sign is employed to indicate the nature of that complexity.

3. Results

A conceptual model, combining relevant constructs from the Health Belief Model, Technology Acceptance Model, and Diffusion of Innovation Model was constructed and is presented in Fig. 1.

In the PtD ARM, "actual usage" is predicted by the construct "adoption readiness", the model's endogenous variable. "Adoption readiness" has several modifying antecedents: "self-efficacy", "perceived ease of use", "perceived usefulness", "trust in organization", and "social system influences". These constructs were extracted from the three foundational theoretical frameworks. All of these constructs are thought to positively correlate with the endogenous variable (adoption readiness), with the exception of "social system influences"; which could correlate positively or negatively, depending on the influence under consideration. In the model, "perceived usefulness" is thought to be modified by "trust in technology", "relative advantage", "reliability", and "compatibility". "Perceived ease of use", is thought to be modified by the "complexity" of the technology and whether the stakeholders have the chance to become familiar with the technology ("trialability" and "observability"). "Self-efficacy" is thought to have modifying effects on "perceived ease of use", as well. The HBM constructs of "perceived risk" and "perceived benefits" are thought to influence stakeholder trust in the PtD technology. Perceptions of the severity of health outcomes and individual susceptibility to health outcomes will impact perceived risks.

4. Conclusions

By taking an integrative approach, the PtD Adoption Readiness Model (PtD ARM) enhances our understanding of the interrelationships of complementary model constructs and factors that influence user adoption intentions of technology innovation, specifically as related to technology that is designed to prevent worker illness. PtD ARM is the first to integrate the HBM, TAM, and DOI frameworks into a synthesized conceptual model for explaining or predicting behavioral

intentions to adopt new technology. As there are documented instances of commercially available, yet poorly diffused, PtD technologies for preventing illness, injury and fatality in the construction industry, a model that can be employed to drive intervention development was needed. Since the U.S. National PtD initiative has, as one of its major goals, the improved diffusion and adoption of these innovations, the PtD ARM could be useful as a foundation for future diffusion intervention strategies and activities.

Development of the PtD ARM was undertaken as a part of an ongoing project to develop intervention strategies to improve PtD adoption in the construction industry sector. Work is currently underway to develop and evaluate intervention strategies that employ PtD ARM constructs. These interventions target the adoption of PtD technology within the drywall finishing trade sector. Long-term goals of the research are to expand intervention strategies into the masonry, asphalt roofing, and welding trades, as well. A validated survey instrument to assess model constructs is under development. Future research phases will include confirmatory structural equation modeling to test assumptions about relationships among model constructs and identify latent variables.

5. Recommendations for future research

This article has elucidated additional priorities for future research. Several PtD solutions to control occupational health risks in construction are not currently commercially available. Additional research and development is needed to design: handheld masonry saws with local-exhaust ventilation, hand-operated surface-finishing grinders with local-exhaust ventilation, water-fed jackhammers, and enclosure systems for stationary masonry saws. Preliminary designs that do exist may require additional empirical assessment of their dust-collection effectiveness and usability aspects.

Several PtD solutions that are commercially available are not currently widely adopted by the construction industry. Additional research is needed to explore the diffusion barriers that are preventing the adoption of these technologies.

Lastly, further study is needed to test the PtD ARM applicability and constructs. Additional study is needed to test the PtD ARM in industrial sectors beyond construction, and for hazards beyond the chemical health hazards identified in the present article.

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