Strengths and weaknesses of experimentation

Construction management (CM) research examines real-world means and methods in an effort to improve the effectiveness and efficiency of the construction industry. The academia has a critical role in developing the new knowledge that construction practitioners need to envision, undertake, and sustain successful innovation. However, the new knowledge created by the academia often does not satisfy the needs of practitioners. One reason for this unfortunate situation is that the research methods used by academics in CM, namely, surveys and case studies, mostly study phenomena that already occurred. That is, these methods focus on existing reality. CM, by epistemology and axiology, is a " proactive" field in that each construction project is an intervention into what exists and thus creates new reality. What is clearly needed in CM is a research approach that combines the objectives of both applied and basic research by contributing to the solution for practical problems and the creation of scientific knowledge at the same time. An approach that fulfills these criteria is experimentation, which is a scientific approach that not only discovers or explains our world but also proves new theories. Theoretical and empirical studies on experimentation are preeminently suited to the investigation of the issue of causality. Reproducibility as a methodological imperative in experimentation produces highly reliable results. Experimentation is fundamentally different from the traditional research approaches in CM such as survey and case study. With these approaches, the researcher tends not to affect or interface with what is being studied. This study considers experimentation not as a method in the form of a positivist laboratory experiment but as a particular analytical approach that includes an array of methods and data collection techniques. In this study, we examine the potential applicability of experimentation in

CM. Although a few reported studies have used this approach in construction, there has been little attempt to elaborate the applicability of the approach in CM. The rest of this paper is organized as follows. First, experimentation is defined, highlighting its strengths and weaknesses, its underlying philosophy, and its application procedure. Second, to demonstrate its use in CM, we present a series of case studies on deriving scientific algorithms to detect impending attacks of heat stress to ensure the health and safety of site personnel working in hot weather. The paper concludes with a discussion and reflection on how experimentation can be a scientific research approach that can enable the academia to influence and improve work practices in the construction industry.

Experimentation is the foundation of science and the scientific method. The pursuit of knowledge is the rationale behind experimentation. For centuries, researchers have relied on systematic experimentation, guided by their insight and intuition, as an instrumental source of new information and the advancement of knowledge. Well-known experiments have been conducted to characterize naturally occurring processes, to decide among rival scientific hypotheses about matter, to find the hidden mechanisms of known effects, and to simulate what is difficult or impossible to research: in short, to establish scientific laws inductively. Some of the popular series of experiments have led to scientific breakthroughs or radically new innovations from which we still benefit today. The Concise Oxford Dictionary defines the term “ experimentation” as a scientific procedure undertaken to make a discovery, test a hypothesis, or demonstrate a known fact. The philosophical roots and the first scientific applications of experimentation data can be traced back to the 17th century. At the beginning of that century, Bacon distinguished between observed experience and experience produced through manipulative human intervention, and Galileo placed experimentation at the very foundation of modern scientific knowledge. Bacon and Galileo are considered the fathers of the scientific method. Science in the 16th century depended on deductive logic to interpret nature. Bacon and Galileo insisted that the scientist should instead proceed through inductive reasoning, from observations to axiom to law. The interplay between deductive and inductive logic underlies how knowledge is advanced. Experimentation can be divided into laboratory tests and field experiments. Laboratory tests attempt to create conditions in which hypotheses about causal powers can be tested in idealized conditions conducive for their expression. Field experiments are conducted where laboratory experiments cannot be undertaken because of the nature of real-life setting. Both types of experimentation share a common core of characteristics. The epistemological paradigm of experimentation can be described as pragmatism in that " truth" is premised upon utility. The characteristics of experimentation that distinguish it from other research approaches are as follows. First, experimentation provides insight into cause-and-effect by demonstrating what outcome occurs when a particular factor is manipulated. Second, experimentation simultaneously assists in practical problem solving and expands scientific knowledge. This goal extends to two important process characteristics: (1) highly interpretive assumptions are made about the observations, and (2) the researcher intervenes in the problem setting.

Steps in Experimentation

Experimentation has a five-phase cyclical process. It is used to provide a reliable description of a phenomenon, which may then be explained through reasoning based on the existing body of knowledge and by employing assumptions, postulates, or hypotheses. The validity of these hypotheses will then be put to test by using them to predict the outcome of further experiments involving the same phenomenon in different circumstances. Experimentation cycles are repeated many times, and the phases may involve coordination among multiple individuals, groups, or departments. A well-defined objective, sequential approach, partitioning variation, degree of belief, and simplicity of execution are the principles of a sound experimentation. As shown in Figure 1, the phases are as follows. Phase 1: Identifying Problem As is true of all research projects, experimentation starts with a clear statement of what is to be studied. In the case of an experiment, not only is the dependent variable identified but also one or more independent variables. The reason for hypothesizing a causal relationship between the independent and the dependent variables should be documented with reference to previous research. Stating the problem leads to the development of certain theoretical assumptions about the nature of the problem domain. Phase 2: Designing the Experiment Designing the experiment refers to the overall strategy about the setting of the experiment, the assignment of subjects to experimental groups, and the order of presentation of the independent variable. Among the factors that have to be considered in the planning of experiments are the ranges of the variables to be covered and the number and spacing of the test points throughout these ranges (Moen et al. 2012). When the researcher has decided what will be measured in the experiment and suitable instruments have been selected for it, the apparatus is assembled and the readings are taken. Phase 3: Executing the Experiment Executing the experiment implements the designed experiments from Phase 2. Importantly, the experimenter should adequately record the work, follow rigorous scientific protocols, and take exact measurements to generate valid results. Conducting a pilot study of the entire experimental procedure is necessary. Analysis of the pilot study reveals the problems of the design, equipment failure, ambiguous instruction, and other aspects in the stage in the research where corrections and adjustments can still be made. Phase 4: Analyzing the Results When the experiment has been completed and the required data have been collected, they have to be interpreted and analyzed. This stage of the research project attempts to answer the question " What do the data reveal?" Generally, tools available for such studies use statistical and graphical methods. When the gathered data comprise a relationship between variables, presenting the results graphically is recommended. Afterwards, the graphs may be represented by empirical equations, perhaps the most concise way in which the data can be summarized. Phase 5: Disseminating the Findings Reporting the findings is an essential stage of the research project. The results and the process by which they were derived need to be accepted by the academic and the professional communities so that the new knowledge becomes another stepping stone in the advancement of the state-of-the-art and face of society. Engaging the practitioners as team members of the research team is conducive in achieving this outcome. Therefore, researchers should collaborate with industry practitioners to establish their credibility.

Strengths and Weaknesses of Experimentation

Experimentation has both strengths and weaknesses. Corbetta (2003) lists two major strengths of this approach. First, it is the research method that provides the best opportunity to establish cause-and-effect relationship. Second, it enables researchers to isolate specific phenomena that cannot be studied systematically in their natural setting because of the presence of other factors that hide, confuse, and distort them or of the background " noise" of everyday life, which masks the signs of the less evident phenomena. Sørensen et al. (2010) argue that the experimental method distinguishes itself from traditional research methods by having a clear focus on real-life problem solving and by following a direct path toward the creation and implementation of practically applicable knowledge while simultaneously creating new and otherwise hardly retrievable scientific knowledge. The difficulties or weaknesses of experimental research include problems in recruiting appropriate subjects, thus limiting the ability to generalize to larger populations, and some risk of injury to subjects. The results of an experiment usually cannot be generalized to an entire population or to sectors of the population different from the study population. Two reasons account for this: inadequate sample size and improper selection criteria of the experimental subjects. Many unexpected things can and do occur despite the best preparations. A researcher working with humans within a laboratory or in the field should, in his/her own best interest and in the interest of each participant, acquire the guidance and the approval of an institutional review board. This step will not only prevent accidents but also protect the researchers from the unconscious misuse of personal information.

Discussion

The objective of this study is to advocate the use of experimentation in CM research through case studies of some recently completed experimental studies. As argued, very few CM studies have used this approach. Even if they did, they seldom provided a full description of the experimental approach and did not provide guidelines for applying it. This study attempts to fill this gap. The feasibility of using experimentation as an alternative approach in conducting CM research has been demonstrated by a series of case studies on heat stress research. Abdelhamid and Everett (2002) used experimentation to investigate the physical demands of construction work and to evaluate whether these physical demands are excessive. Nystrom (2008) employed the experimental method to evaluate partnering projects based on a new type of data. These studies suggest that experimentation can be a valuable methodological approach that provides complementary procedures and scientific knowledge similar to traditional CM research methods. Experimentation can also provide new knowledge that can be theorized. Through observations during experiments, the researcher may discover new social behavior, new structures, and trends that would not have been discovered using traditional non-experimental methods. Gibbons et al. (1994) argue that a new form of knowledge production (Mode 2 knowledge) is emerging, which is context driven, problem focused, and interdisciplinary. It differs from traditional research (Mode 1 knowledge), which is academic, investigator initiated, and discipline based knowledge production. Therefore, the use of experimentation strengthens the tendency toward Mode 2 research that emphasizes scientific results simultaneously with solving practical problems. Research in CM is closely interwoven with the activities of a particular community of practice, namely, the construction industry. Experimentation can be used in deriving solutions for complex and practical problems in the construction industry. Evidently, based on the examples and the cases reported in this paper, experimentation provides a structured approach to conduct research while maintaining a high level of academic rigor and permitting the application of results to a wider audience. It is highly suitable for conducting research in construction, especially in multidisciplinary research that involves technological, organizational, and behavioral aspects. It is also a useful method for subjects involving multiple parties, such as partnering, alliancing, and virtual teams/organizations. Experimentation provides an answer to the criticism that academic researchers and the construction industry practitioners traditionally do not involve themselves in most construction research projects. Construction practitioners perceive that academic research is more focused on subjects and issues that are not relevant to the construction industry. Some practitioners opine that academic research is inapplicable and impractical for use in real-life construction projects. Conversely, researchers argue that practitioners often do not entertain innovative research ideas that require a major change in the industry practices and procedures. This situation results in the need for enhancing researcher-practitioner collaboration to conduct research on problems that are vital for the construction industry and to derive adoptable solutions. Experimentation provides a platform to achieve this objective. The cases described in this paper are good illustrations of how this can be achieved. Experimentation is a powerful methodology to empirically establish causal claims between the dependent variables and the independent variables. The independent variables are then manipulated by the experimenter under carefully controlled conditions to determine any changes in the dependent variables. Therefore, experimentation is designed to determine whether or not this cause-and-effect relationship actually exists. The cause-and-effect relationship is the basis of scientific reasoning. Unfortunately, traditional CM research methods (e. g., survey and case study) do not reveal unambiguous causal relationships, and CM researchers often assume that causal linkages have been demonstrated and design programs around inadequate knowledge about what the consequence of certain actions may be. However, experimentation is not without problems for researchers. One problem discovered in the reported experiments concerns the generalization of the results. Generally, the results of laboratory experiments may be generalized to other laboratory settings in the same way, but what happens in real life is another story. Similarly, a field experiment may not be able to give generalized knowledge about what will happen in other contexts because of its context dependence. Factors such as type, age, and organization may influence the results of different experiments. This problem of generalization is by no means a problem that only concerns the experimental method only, but it is also a problem that all research methods face. Moreover, experimentation is usually expensive in terms of the time involved and the labor expended, even as it is essential to innovation. What has changed, particularly given the new technologies available, is that it is now possible to perform more experiments in an economically viable way while accelerating the drive toward innovation.

Conclusion

A key objective of this study is to provide guidelines for conducting research using the experimentation approach. We followed the process of canonical experimentation described in an earlier section in the case studies described in this paper. Using experimentation to conduct CM research can be challenging. The large size of the industry puts extreme requirements on establishing research findings that are applicable to the entire or even a section of the industry. One of the inherent problems is the cost involved in observing a sample size large enough to produce data points that are statistically significant. Despite its challenges, the experimentation approach can provide practically applicable knowledge with the potential to increase the scientific elements in a much more direct way than knowledge created from the traditionally applied methods in CM research. This study illustrates how different experimental methods may deal with the complexity of CM research. Therefore, as CM research becomes increasingly complex, experimentation should be considered as a serious and central research strategy for future research. It can be combined with other research methods to generate new theory and/or to reinforce or contradict existing theory.