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Quasi-experimentation – An Alternative Approach for Conducting Construction Management Research

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Abstract

Construction management (CM) as an applied academic discipline has a dual mission of creating scientific knowledge and solving practical problems. To do so, proper research approaches are required. Traditionally, CM research has been based primarily on either quantitative surveys or case studies. In this study, experimentation is advocated as a feasible and reliable approach to conduct CM research. Experimentation facilitates the creation and discovery of knowledge and thus leads to the improvement and development of a real setting. This study describes the underlying philosophy and application procedure of experimentation, and highlights its strengths and weaknesses. The applicability of the approach to CM is illustrated through a case study on heat stress research. The findings indicate that experimentation is a rigorous, structured, and reliable research approach that is viable for conducting CM research, which enables the academia to influence and improve work practice in the construction industry.

It also fosters better collaboration between industry practitioners and the academia in the quest for excellence in the industry.

Keywords: Experimentation; Construction management research; Quasi-experiment; Field studies; Focus group meeting

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Introduction

Construction management (CM) research examines real-world means and methods in an effort to enhance the efficiency and effectiveness of the construction industry (Lucko and Eddy 2010). The academia has a critical role in developing new knowledge that construction practitioners need to undertake, sustain and envisage successful innovation. However, the new knowledge created by the academia often does not satisfy the needs of practitioners (Sexton and Lu 2009). 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 (Azhar et al. 2010).

CM is a diverse field attracting a wide variety of researchers who are approaching their object of study from different disciplinary and methodological perspectives (Knight and Ruddock 2008). Any scientific study requires researchers to ensure proper research design and methodology. In broad terms, CM research either adopts an objective "CM" orientation, where the focus is on the discovery of something factual about the world it focuses on, or a subjectivist approach, where the objective is to understand how different realities are constituted (Harty and Leiringer 2007). Whilst the former emphasizes causality, the latter focuses on localized subjective meaning. However, CM research is associated with inherent difficulties such as a lack of scientific rigor, the incapability to replicate procedures, the challenge in the application of results to a wider population, and a lack of dissemination because of concerns about propriety information (Hauck and Chen 1998). In essence then, CM research, in its current form, does not prioritize abstraction and extraction of a posteriori knowledge.

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What is clearly needed in CM is a research approach that combines the objectives of both applied and basic research by creating scientific knowledge and contributing to the solution for practical problems at the same time (Azhar et al. 2010). An approach that fulfills these criteria is experimentation, which is a scientific approach not only discovers or explains our world but also proves new theories (Bernold and Lee 2010). It is an established research approach that has been used in other applied disciplines such as medicine (Steadman 1998), engineering (Mølhave 2008), biology (Newsam and Schüth 1998), psychology (Furnham and Heyes 1993), and social science (Morris and Bàlmer 2006), to name a few. Theoretical and empirical studies on experimentation are preeminently suited to the investigation of the issue of causality (Radder 2003). Reproducibility as a methodological imperative in experimentation produces highly reliable results (Hones 1990; Greenberg et al. 2003). 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 (Naoum 2001).

This study considers the 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 (Sørensen et al. 2010). In this study, we examine the potential applicability of experimentation in CM. Although a few reported studies have used this approach in construction (Abdelhamid and Everett 2002; Nystrom 2008; Schlagbauer et al. 2011), 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 underlying philosophy and application procedure, and its strengths and weaknesses. Second, to demonstrate its use in CM, we present a case study on deriving scientific algorithms to detect impending attacks of heat stress. The paper concludes with a discussion and reflection on the benefits and challenges for using experimentation in CM.

Experimentation

Experimentation is the foundation of science and the scientific method. Thomke (2003) considers the pursuit of knowledge as the rationale behind experimentation. Systematic experimentation, coupled with intuition and insight, enable researchers to advance knowledge and generate new source of information. Thomke (2003) reports that well-known experiments have been conducted to decide among rival scientific hypotheses about matter, to find the hidden mechanisms of known effects, to characterize naturally occurring processes, 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 resulted in radically new innovations or scientific breakthroughs.

The word *research* has its origin in a term which means “to go around” or “to explore” and was derived from an even earlier “circle”. *Experiment* means to “try” or “test” and refers to some of the procedures used in trying to discover to unknown facts (Plutchik 1983). As the definitions of these terms suggest, experimentation refer to the process of exploration and testing used to achieve a fuller understanding of the nature of the world. 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

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very foundation of modern scientific knowledge. Bacon and Galileo are considered the fathers of 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 (Radder 2003).

Experimentation can be divided into laboratory tests and field experiments (Chadwick et al. 1984). Laboratory tests attempt to construct conditions in which hypotheses about causal relationships can be tested in perfect conditions. Field experiments become necessary when laboratory experiments cannot be undertaken because of the nature of real-life setting (Chadwick et al. 1984). Randomized experiment (an experiment in which units are assigned to receive the treatment or an alternative condition by a random process), quasi-experiment (an experiment which units are not assigned to conditions randomly), and natural experiment (not really an experiment because the cause usually cannot be manipulated) are the terms used in describing modern experimentation (Shadish et al., 2002). The common attribute in all experiments is control of treatment (though control can take many different forms) (Shadish et al., 2002). Mosteller (1990) writes, "In an experiment the investigator controls the application of the treatment"; and Yaremko, Harari, Harrison and Lynn (1986) write, "one or more independent variables are manipulated to observe their effects on one or more dependent variables." In response to the needs and histories of different sciences, many different experimental subtypes have developed over time (Winston 1990; Winston and Blais 1996).

Steps in Experimentation

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Experimentation has a five-phase cyclical process (Brinkworth 1973). 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 (Brinkworth 1973). A well-defined objective, sequential approach, partitioning variation, degree of belief and simplicity of execution are the principles of a sound experimentation (Srinagesh 2006). As shown in Figure 1, the phases are as follows:

(Please insert Figure 1 here)

Phase 1: Identifying Problem

In order to conduct research, it is first necessary to identify a problem in need of a solution. Researchable problems arise from several traditional sources: theories, practical issues, and past research (Johnson and Christensen 2004). Literature relevant to the problem should be reviewed to reveal the current state of knowledge about the selected topic (Christensen 2004). As the researcher does a more comprehensive review of the literature relevant to the proposed study and an initial assessment of resources (e.g., time, expense, expertise of the researcher, type of research participants, and ethnical sensitivity), he/she may make a clear and exact statement of the problem to be investigated and set down hypotheses. These must be formalized because they represent the predicted relation that exists among the variables under study. Often, hypotheses are a function of past research. If they are confirmed, the results not only answer the

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question asked but also provide additional support to the literature that suggested the hypotheses (Christensen 2004).

Phase 2: Designing Experiment

The design of a research study is the basic outline of the experiment, specifying how the data will be collected and analyzed and how variation will be controlled. The design determines to a great extent whether the research question will be answered. A credible research design in one that maximized validity-it provides a clear explanation of the phenomenon under study and controls all possible confounds or biases that could distort or cloud the research findings (Singleton and Straits 2010). Four types of validity (i.e., statistical conclusion validity, construct validity internal validity, external validity) are typically considered in the design of experimental research (Bickman 1989; Cook and Campbell 1979).

The researcher anticipates the amount of data that will be needed to conduct the study. Type of sample or sampling procedure used and the sample size are two initial questions to the sampling plan. Good science typically involves probability-based sampling (an example of which is a "random" sample) to minimize the chance of bias within the data (Abowitz and Toole 2010). Statistical conclusion validity is an important factor in the planning of research. It concerns primarily those factors that might make it appear that there were no statistically significant effects when, in fact, there were effects. The greater the ability of the research detects effects that are present, the greater the statistical power of the study (Babbie 2005). Data are useless if they are not valid, accurate and reliable. The construct of validity is relevant whether one is collecting primary data or using extant data. The researcher is concerned that the variables used in the study are strong operationalizations of key variables in the study's conceptual framework (Bickman and

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Rog 1998). When conducting an experiment, we want to identify the effect produced by the independent variable. If the observed effect, as measured by the dependent variable, is caused only by the variation in the independent variable, then internal validity has been achieved. To make this causal inference and attain internal validity, the researcher must control for the influence of extraneous variables that could serve as rival hypotheses explaining the effect of the independent variable (Campbell 1957; Christensen 2004). In order to generalize the results of a study, we must identify a target population of people, settings, treatment variations, outcome measures, and times and then randomly select individuals from these populations so that the sample will be representative of the defined population (Bracht and Glass 1968; Orr 2004).

It is of great importance to choose which type of research design is most appropriate for a particular research study. The choice requires a thorough knowledge of the research problem, of the extraneous variables to be controlled, be possible to generalize the result, and of the advantages and disadvantages inherent in the alternative design available. For this reason, researchers would be well-advised to consider a variety of designs before making their final choices. Researchers should evaluate each design relative to the potential validity threats that are likely to be most plausible in their specific research contexts.

Phase 3: Executing Experiment

Executing experiments implements the designed experiments from Phase 2. Importantly, the researcher should adequately record the work, follow rigorous scientific protocols, and take exact measurements to generate valid results. Carrying out an experiment is much like producing a play. There are "scripts" to write and rewrite; a sequence of "scenes", each contributing something vital to the production; a "cast" of experimental assistants to recruit and train; "props" and "special effects"; and "rehearsals." (Singleton and

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Straits 2010) Figure 2 shows the key points in executing an experiment. Pre-tests are carried out on a few preliminary subjects to see how the experimental procedures affect them. Analysis of the pretesting 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 (Lancaster et al. 2004). Before the start of the 'production', subjects must be recruited and the investigators must obtain the subjects' informed consent to participate. The first 'scene' of an experiment consists of some sort of introduction of the study. Basically, this involves an explanation of the purpose or nature of the research, together with instructions to the subject. The manipulation of the independent variable may be thought of as the second 'scene' of the experiment. This is the point at which some set of stimuli is introduced that serve as an operational definition of the researcher's independent variable and to which the subject is expected to respond (Singleton and Straits 2010). An immediate way to obtain evidence that the manipulation of the independent variable was experienced or interpreted by the subject in the way the researcher intended is to incorporate some sort of manipulation check into the experiment. The dependent variable, which always follow the introduction of the independent variable, is measured in experiments with either self-reports or observations. The closing 'scene' of the experiment is a debriefing session in which the researcher discusses with the subject what has taken place.

(Please insert Figure 2 here)

Presentation and manipulation of the independent variable requires the active participation of the investigator, and the measurement of the dependent variable involves the administration of a variety of assessment instruments. Use of automatic recording devices can reduce the likelihood of making a

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recording error as a function of researcher expectancies or some type of observer bias. Microcomputers are also used frequently in experimentation both for the presentation of stimulus material and for the recording of dependent variable responses. The use of microcomputer has given the researcher an extremely flexible tool. In addition to the use of microcomputer, advances in technology and interdisciplinary research have enabled researcher that would have been impossible several decades ago (Thomke 2003).

Phase 4: Analyzing Results

When the experiment has been completed and the required data have been collected, the investigator must make a decision as to whether to reject the null hypothesis. The most appropriate procedure for testing the null hypothesis is to analyze the data using one of the avail1able statistical tests. Every experimental study involves one or more independent variables, several levels of which are administered either to a single group of participants or to different groups of participants. These factors dictate the type of statistical analysis (e.g., t-test, one-way analysis of variance) to be applied to the data (Christensen 2004). 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 (Brinkworth 1973).

Phase 5: Disseminating Findings

Reporting the findings is an essential stage of the research project. The process and the results by which they were derived need to be accepted by the professional communities and the academia so that the new knowledge becomes another stepping stone in the advancement of the state-of-the-art and face of society (Lucko and Eddy 2010). Reporting research most frequently takes place through the professional journals in a field. Engaging the practitioners as 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 is the primary tool for studying causal relationships. However, like all research methods, experiments have both strengths and weakness. Christensen (2004) lists three major strengths of this approach: causal inference, control and ability to manipulate variables. The experiment has been presented as a method for identifying causal relationships. Indeed, its primary advantage is strength with which a causal relationship can be inferred. The inferential strength that the experimentation has in identifying a causal relationship is, to a large degree, obtained from the degree of control that can be exercised. Control is the most important characteristic of the scientific method, and the experimentation enables the researcher to effect the greatest degree of control. Another advantage of the experimentation is the ability to manipulate precisely one or more variables of the researcher’s choosing. The experimentation enables one to control precisely the manipulation of variables by specifying the exact conditions of the experiment. The results can be then interpreted unambiguously, because the research participants should be responding primarily to the variables introduced by the researcher. Sørensen et al. (2010) argue that the experimentation distinguishes itself from traditional research approaches by focusing 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 most frequently cited and probably the most severe criticism leveled against the experimentation is that laboratory findings are obtained in an artificial and sterile atmosphere that procedures any

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generalization to a real-life situation. The following statement by Bannister (1966) epitomized this point of view: "*In order to behave like scientists we must construct in which subjects are totally controlled, manipulated and measured. We must cut our subjects down to size. We must construct situations in which they can behave as little like human beings as possible and we do this in order to allow ourselves to make statements about the nature of humanity.*" Some experimental designs avoid these particular problems by moving outside the laboratory into a more natural social setting. Conducting experiments in such settings increases lowers the degree of control and threats to the internal validity of a study. Extraneous variable that confounds the results of an experiment should be controlled to accurately infer that a causal relationship exists between the independent and dependent variable. Furthermore, the field experimentation may not be able to provide generalized knowledge on what will occur in other contexts because of its context dependence (Sørensen et al. 2010).

Additional difficulties of the experimentation include the fact that the experiment may be extremely time consuming and the problems in designing the experiment (Thomke 2003). A researcher always has to go to extreme lengths to set the stage for, and motivate the participant. Then, when the experiment is actually conducted, the researcher is often required to spend quite some time with each participant. 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 the Institutional Review Board for the Protection of Human Subjects in Research (IRB). This step will not only prevent accidents but also protect the researchers from the unconscious misuse of personal information (Bernold and Lee 2010).

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Experimentation in CM

Modern experimental research still uses traditional basic elements, although these elements are augmented with sophisticated tools and methods. However, researchers conducting scientific experiments in the field of construction experience harsh working conditions. A scientific experiment aims to establish empirical evidence of the relationship between an independent variable and a dependent variable that is being effected by it. The keys to this process are observations and measurements taken with calibrated instruments to establish causalities unaffected by extraneous factors caused by uncontrollable variables (Montgomery 2012). One serious difficulty is the many uncontrollable variables that bring about such unwelcome extraneous effects. Construction is essentially a social process (Abowitz and Toole 2010). Construction is the application of technology to achieve goals involving the erection or retrofitting of infrastructure and buildings. The processes described in this definition of construction are all social activities (Abowitz and Toole 2010). Because of safety and scheduling concerns, contractors do not allow experimental testing of a new device or method in a construction project. Repetitive experiments in a stable environment can be conducted only in strictly controlled laboratories. Experiments involving test on a construction site require a different approach.

Legal, ethical, and practical considerations preclude the use of a true experimental design in several research situations. A true experiment is an experiment with units randomly receiving treatment or randomly set in alternative conditions (Shadish et al. 2012). Subjects often cannot be randomly assigned. Sometimes, control or comparison groups cannot be incorporated into the design. At other times, treatment and control groups can be randomly assigned, but the researcher cannot exercise tight control over subjects' experiences required for a true experiment (Gerbal and Green 2012). To solve these problems, researchers

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have developed several quasi-experimental designs (i.e., research design with a nonrandomized comparison group; one-group research design with posttest measure; research design with comparison group and posttest; one-group research design with pre-test and post-test measure), so named because they take an experimental approach without full experimental control (Campbell and Stanley 1963).

A quasi-experiment is an empirical study that estimates the effect of an intervention on its target population (Gerber and Green 2012). Using quasi-experimental designs minimizes threats to external validity because natural environments do not suffer the same problems associated with artificiality as well-controlled laboratory settings (Reichardt and Mark 1998). The findings of quasi-experiments may be applied to other subjects and settings and thus allow generalizations about the population. This experimentation method is efficient in longitudinal research, which involves long periods and allows follow-up in different environments. Quasi-experiments also allow researchers to manipulate any variable (Derue et al. 2012). Using self-selected groups in quasi-experiments leaves to chance the solution to the ethical and condition-related concerns of the study. These features of quasi-experimentation are highly prized in CM research.

Quasi-experimentation in CM: A Case Study

The applicability of experimentation approach in CM is demonstrated through a case study of deriving scientific algorithms to detect impending attacks of heat stress. The incidence of heat stress in the construction industry has been alarming and caused a number of verifiable reported deaths in Hong Kong (Apple Daily 2007&2010). It was reported that 28 percent of construction workers in Hong Kong have suffered heat related illness (Hong Kong Daily News 2012). The Construction Industry Council (CIC)

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addresses this important issue by setting up an Informal Task Force on Working in Hot Weather, and promulgated a series of basic notes and guidelines on site safety measures in hot weather. These notes and guidelines cover appropriate work arrangements, breaks and cool down facilities, drinks, clothing and protective equipment, maintaining the health of workers, as well as first aid procedures and facilities (Construction Industry Council 2008; Department of Health 2008; Labour Department 2010). However, their recommendations are by and large some "dos and don'ts" and are not based on scientific measurements (Chan et al. 2012a). The continuing high frequency of heat related incidents in the Hong Kong construction industry calls for better approaches in deriving scientific algorithm to detect impending attacks of heat stress. Using experimentation approach, a research protocol was developed to address this pressing issue (see Figure 3). Further details of these studies can be found in Chan et al. (2012b).

(Please insert Figure 3 here)

Description of the Research Process

Phase 1: Identifying Problem

Earlier naturalistic observation-based research by Chan et al. (2012c) has computed the maximum duration (Heat Tolerance Time) that a rebar worker could work continuously without jeopardizing his health. Naturally workers should be allowed to take a rest when such a threshold is reached. However, how long the workers should be allowed to recover in hot weather after working to exhaustion remains to be answered (Chan et al. 2012b). Recovery can play a considerable role in the well-being of rebar workers as well as in their productivity (Maxwell et al. 2008). Sufficient rest can prevent a loss of productivity and the accumulation of fatigue. A lack of recovery can interfere with their productivity and also induce emotional,

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cognitive and behavioral disturbances, which can subsequently lead to heat syndromes especially in hot and humid environment. The main purpose of the study was to assess the effect of recovery time on workers' energetic recovery, and determine the optimal recovery time after working to exhaustion in hot and humid environment (Chan et al. 2012b).

Phase 2: Designing Experiment

Field studies were conducted during the summer time in Hong Kong (from July to August of 2011). Nineteen apparently healthy and experienced rebar workers were invited to participate in this research study. Exclusion criteria included: flu in the week prior to participation, and history of diagnosed major health problems including diabetes, hypertension, cardiovascular disease, neurological problem and regular medication intake. The participants performed tasks of fixing and bending steel reinforcement bars under direct sunlight until voluntary exhaustion and then were allowed to recover under shade until their physiological conditions returned to the pre-work level or lower. Physiological Strain Index (PSI) was used as a yardstick to determine the rate of recovery. Rate of recovery is defined as the percentage of recovery with respect to participant's PSI min and is expressed mathematically as Eq. (1) (Chan et al. 2012b).

$$\text{Rate of recovery} = PSI_{min} / PSI_{i} \quad (1)$$

where PSI_{i} are 5-minute interval measurements taken whilst the participant rested for recovery on site; and PSI_{min} is the minimum value whilst the participant rested on site prior to work.

The quasi-experimental design satisfies three criteria: (1) the design tests the hypothesis advanced-increasing rest time will reduce workers' heat strain; (2) extraneous variables were controlled

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(e.g., participants, environment, type of work, place of rest, protocol) so the observed effects of independent variable (rest time) can be attributed; (3) it is possible to generalize the results. While the hypothesis sounds simple, the difficulty lies in the design of experiments that produce data that create clear causal relationships between rest time and the workers' heat strain. Since most construction takes place within an uncontrollable environment many extraneous influences may "sneak in through backdoors" to create misleading correlations. Figure 4 shows the quasi-experimental design with minimal impact of extraneous variables.

(Please insert Figure 4 here)

Phase 3: Executing Experiment

Participants were informed of the purposes and procedures to be employed by the study before commencement of any tests. When the participants arrived at their working place, they were asked to rest in seated posture for another 20 min to calm down and acclimatize themselves to the hot and humid environment. Four sets of PSI were measured (at 5 min interval) in these 20 min. The minimum PSI (PSI_{min}) was taken as a yardstick for comparison after the participants had worked to exhaustion to determine the recovery rate. During the work, participants performed steel bar bending and fixing tasks as per their usual daily work routine. Voluntary exhaustion is defined as a state of self-awareness when one starts to feel a general inability to physically continue to perform at the desired level due to all energy stores having been consumed. It was measured by Rating of Perceived Exertion (RPE-10 point scale) in the current study. Voluntary exhaustion was reached when the participants reported a RPE of 10 or stopped working voluntarily, whatever come first, indicated that they could not continue working anymore. The participants were then allowed to recover on site until their physiological conditions fully recovered. Full recovery was reached when the post-work PSI returned to the minimum level or lower.

Phase 4: Data Analysis

One-way analysis of variance (ANOVA) was conducted to test hypothesis. Significant difference between dependent variable (rate of recovery) and independent variables (recovery time) was found. Curve estimation was employed to determine the relationship between recovery time and rate of recovery, with former as the independent variable and latter as the dependent variable. The average PSI values at 5-minute intervals were calculated to construct a curve for the rate of recovery. Curve estimation results show that recovery time is a significant variable in predicting the rate of recovery ($R^2 = 0.99$, $P < 0.05$). The curve can be represented mathematically as Eq. (2) (Chan et al. 2012b).

$$R = 0.001T^3 - 0.069T^2 + 3.174T + 43.764 \quad (2)$$

where T is recovery time (min); and R is rate of recovery (%).

The cumulative recovery curve indicated that on average a rebar worker could achieve 58% in 5 min; 68% in 10 min; 78% in 15 min; 84% in 20 min; 88% in 25 min; 92% in 30 min; 93% in 35 min; and 94% recovery in 40 min (Chan et al. 2012b). In general, the longer they have the resting period, the better the recovery of their strength but the rate of recovery has a diminishing effect with increased recovery time.

Phase 5: Disseminating Findings - Industry Forum

The research team organized several open forums to disseminate the findings and solicit views from

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various stakeholders, namely, Labour Department, Occupational Safety Health Council, Hong Kong Observatory, major developers, contracting/subcontracting organizations, and trade union representatives. In order to ensure the validity of the survey results, all the respondents should have more than 5 years working experience in the occupational health and safety. A feedback questionnaire was administered at the end of these forums to solicit the attendants' views of the findings and their agreement to the proposed strategies. Based on 87 valid questionnaire replies collected from the industry forum, majority of respondents expressed high level of agreement that "a twenty minute (20 min) rest time should be introduced in the morning when the Very Hot Weather Warning is issued by the Hong Kong Observatory" (a mean agreement score of 3.8 by a Likert scale from 1 to 5; where 1 means "strongly disagree", and 5 means "strongly agree"). The respondents also supported that "outdoor working activities should be temporarily suspended if the temperature reaches or exceeds 35°C" (a mean agreement score of 3.7). The details of the 87 respondents are summarized in Figure 5.

(Please insert Figure 5 here)

Discussion

The objective of this study is to advocate the use of experimentation in CM research through a case study of recently completed experimental study. It was argued that very few CM studies have used this approach. Even if they did, they seldom provided a full description of the experimental approach, nor did they 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. It suggests that experimentation could be a valuable methodological

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approach that provides scientific knowledge and complementary procedures with traditional CM research methods. Experimentation can also contribute to new knowledge which could be theorized. Through observations during laboratory tests or field experiments, the researcher may explore novel social behavior, new trends, and unique structures that would not be found by adopting traditional research approaches.

Benefits of Using Experimentation in CM

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 population. It is highly suitable for conducting research in construction especially in multidisciplinary research that involves organizational, technological, and behavioral aspects. It is also a useful method for subjects involving multiple parties, such as partnering, alliancing, and virtual teams/organizations (Sørensen and Mattsson 2008; Mattsson 2009).

Gibbons et al. (1994) argue that a new form of knowledge production (Mode 2 knowledge) is emerging which is problem-focused, context-driven and interdisciplinary. It differs from traditional research (Mode 1 knowledge) which is investigator-initiated, academic and discipline-based knowledge production. Therefore, the use of experimentation strengthens the tendency toward Mode 2 research that emphasizes scientific knowledge simultaneously with assisting in practical problems solving (Nowotny et al. 2001). 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 (Van Aken 2004).

Experimentation is a powerful methodology to empirically establish causal claims between the dependent variables and the independent variables (Chadwick et al. 1984). 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.

Experimentation provides an answer to the criticism that traditionally, academic researchers and the construction industry practitioners do not interact closely in most construction research projects. Construction practitioners perceive that academic study is more concentrated on issues and subjects that are not relevant to the construction industry (Azhar et al. 2010; Laufer et al. 2008; Rahman and Kumaraswamy 2008). Some practitioners opine that academic research is inapplicable and impractical for use in practical construction projects. Conversely, researchers argue that practitioners often do not contemplate innovative research ideas that need a significant change in the industry procedures and practices (Azhar et al. 2010). This situation results in the quest for fostering better collaboration between researcher and practitioner to conduct CM research on issues that are essential for the construction industry and to derive eligible solutions. Experimentation provides a platform to achieve this objective. The case described in this paper is good illustrations of how this can be achieved.

Challenges for Using Experimentation in CM

Using experimentation to conduct CM research is challenging. Like many social science concepts, many CM terms are imprecise, having meanings that vary between researchers and research contexts. Thus,

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effectively researching CM topics requires the explicit definition of theoretical concepts ("constructs" in the social sciences) at the beginning (Abowitz and Toole 2010). This definition should be maintained throughout the research process. Social science methods often interchangeably use terms, concepts, and constructs, which are theoretical labels for traits or characteristics that exist analytically on the abstract level but are directly unobservable (Abowitz and Toole 2010).

Finding economic means to improve the quality, safety, and productivity of construction requires the development of a posteriori knowledge about the effect of various factors. However, measurable evidence required to support a hypothesis or theory is difficult to produce in the construction industry. Many construction researchers can establish plausible theoretical connections and constant conjunctions but have difficulty with temporal precedence and spuriousness (Abowitz and Toole 2010). The challenge in establishing temporal precedence is that it is usually done by observation and, in the strictest sense, requires controlled experiments involving individuals and companies to observe the effects of manipulating the independent variable.

The large size of the industry imposes extreme requirements on establishing research findings applicable to all or some statistically significant data points produced. The inherent problem is the cost involved in observing sample sizes large enough to produce statistically significant data points. The current case study is limited in sample size. Research with large sample sizes should be conducted to verify the current findings. Collecting substantial evidence is necessary but insufficient to discover and establish knowledge. The effectiveness of a new device, method, or material in the field of construction is difficult to measure. The most important differences are the many extraneous factors that interfere with the independent

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variable and the difficulties in measuring meaningful values with sufficient reliability (Christensen 2004). Measurement validity is the fact that an indicator measures what it is supposed to measure. An invalid indicator causes systematic error or bias in measurement and resulting data. Thus, construction researchers have been challenged to develop experimental procedures within the given constraints while finding ways to collect data that address their hypothesis.

CM experiments are often difficult to perform. Such experiments are often the product of coordination between researchers and people who conduct interventions or furnish data on the outcome of subjects (Gerbal and Green 2012). Orr (1999) and Gueron (2002) describe how such partnerships are formed and nurtured during collaborative research. Both authors stress the importance of building a consensus on using random assignment. Research partners and funders sometimes balk at the idea of randomly allocating treatments and instead prefer to treat everyone or a hand-picked selection of subjects. The researcher must be prepared to formulate an acceptable experimental design and to convincingly argue that random assignment is both feasible and ethical. Successful implementation of the agreed-upon experimental design —the allocation of subjects, the administration of treatments, and the measurement of outcomes—requires planning, pilot-testing, and constant supervision (Orr 1999). Despite the emergency of digital tools that alleviate the burden of a continuous time study, work sampling is still the main workhorse in the construction industry where the pace of the work is not controlled by robots or a conveyer (Bernold and Lee 2010).

Concluding Remarks

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. The application of experimentation in the context of construction management introduces unique challenges and creates new opportunities for researchers.

Experimentation can be a scientific research approach that can enables the academia to influence and improve work practices in the construction industry. However, using experimentation to conduct CM research can be challenging in terms of large size of the industry, appropriate experimental design, and implementation of experiment. Despite its challenges, the experimentation approach can contribute practical knowledge with the inherent capacity to increase the scientific elements in a more straightforward way than knowledge generated from traditional CM research methods. This study illustrates how different experimentations could deal with the complexity of CM research. Hence, as CM research becomes increasingly complexity, experimentation should be regarded as a central and serious 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.

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Figure Caption List

Fig. 1 Experimentation cycle

Fig. 2 Key points in executing an experiment

Fig. 3 Main phases in experimental research

Fig. 4 Quasi-experimental design with minimal impact of extraneous variables

Fig. 5 Average scores indicating respondents' level of agreement

Figure 1

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Figure 1 Experimentation cycle

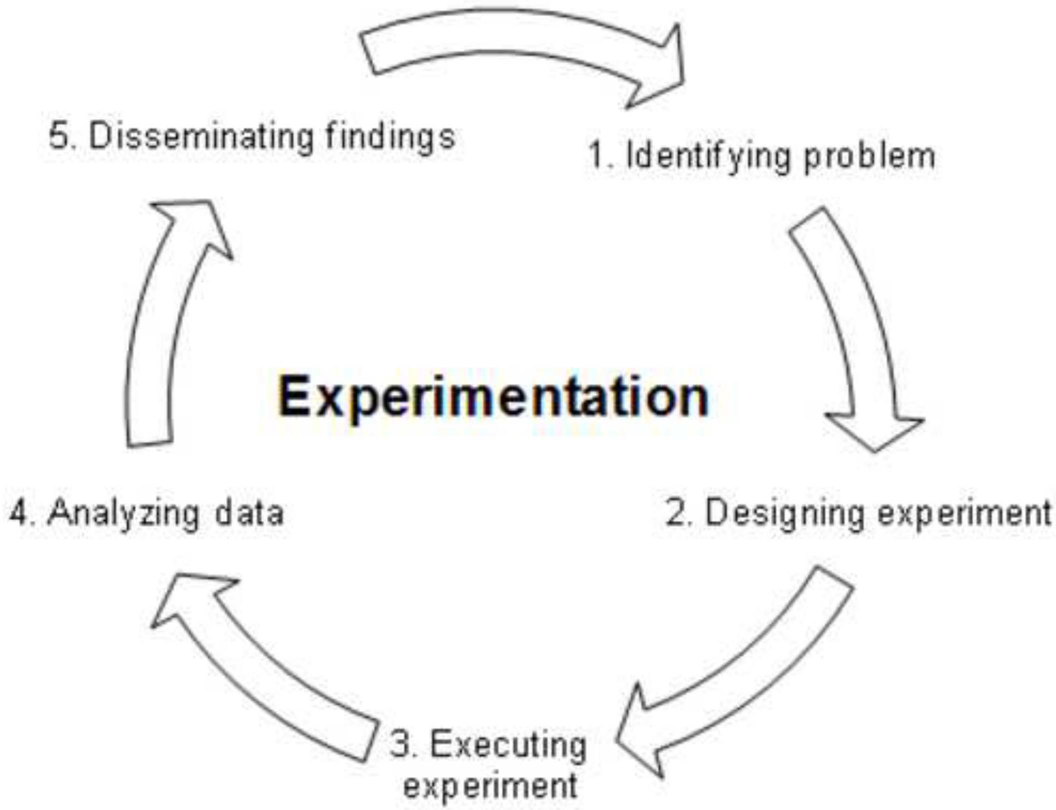

Figure 2

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Figure 2 Key points in executing an experiment

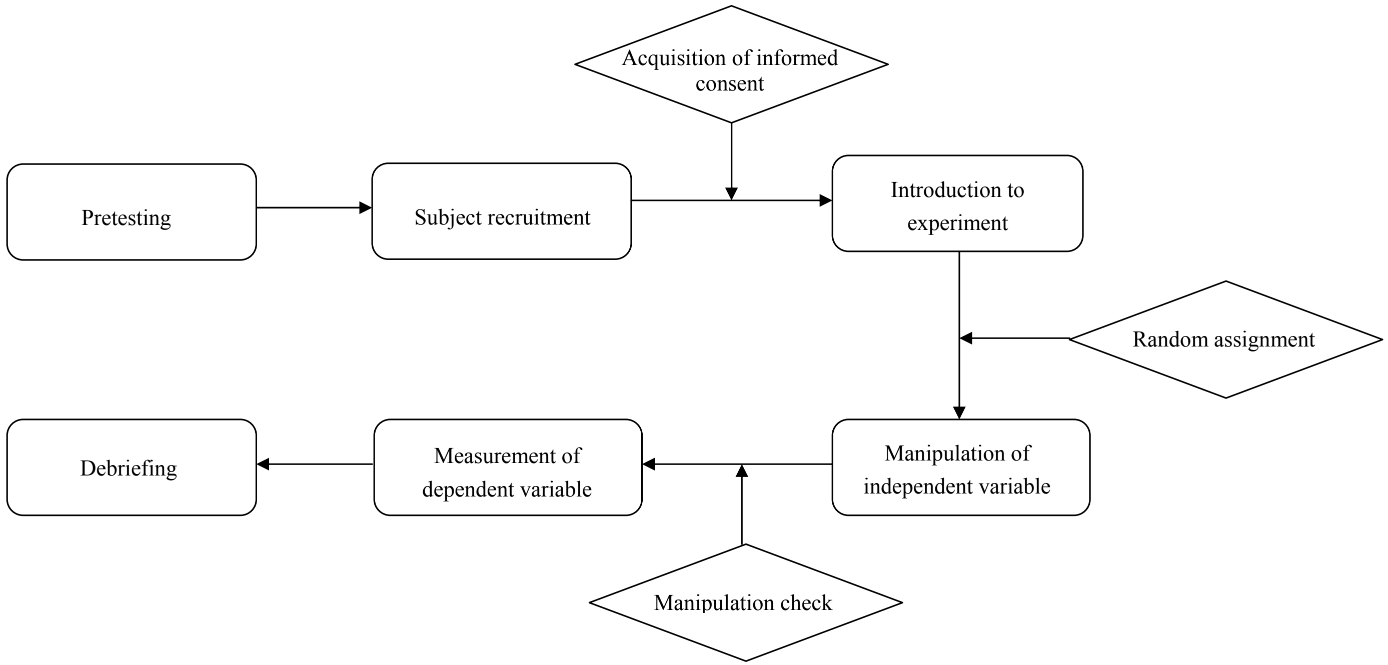

Figure 3

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Figure 3 Main phases in experimental research

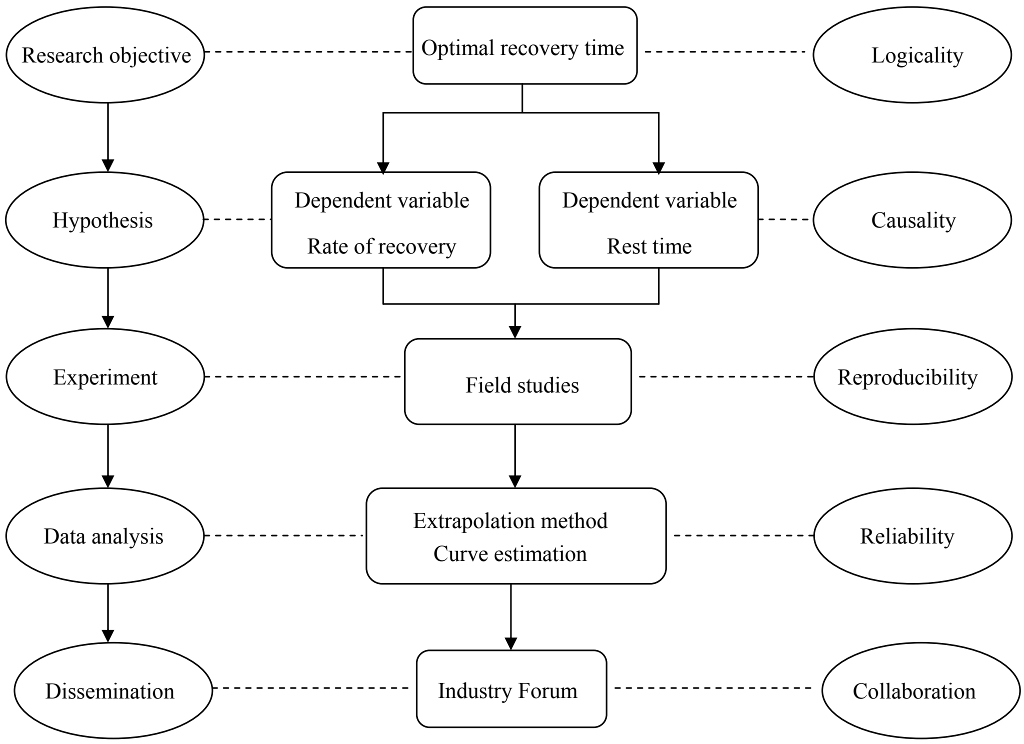

Figure 4

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Figure 4 Quasi-experimental design with minimal impact of extraneous variables

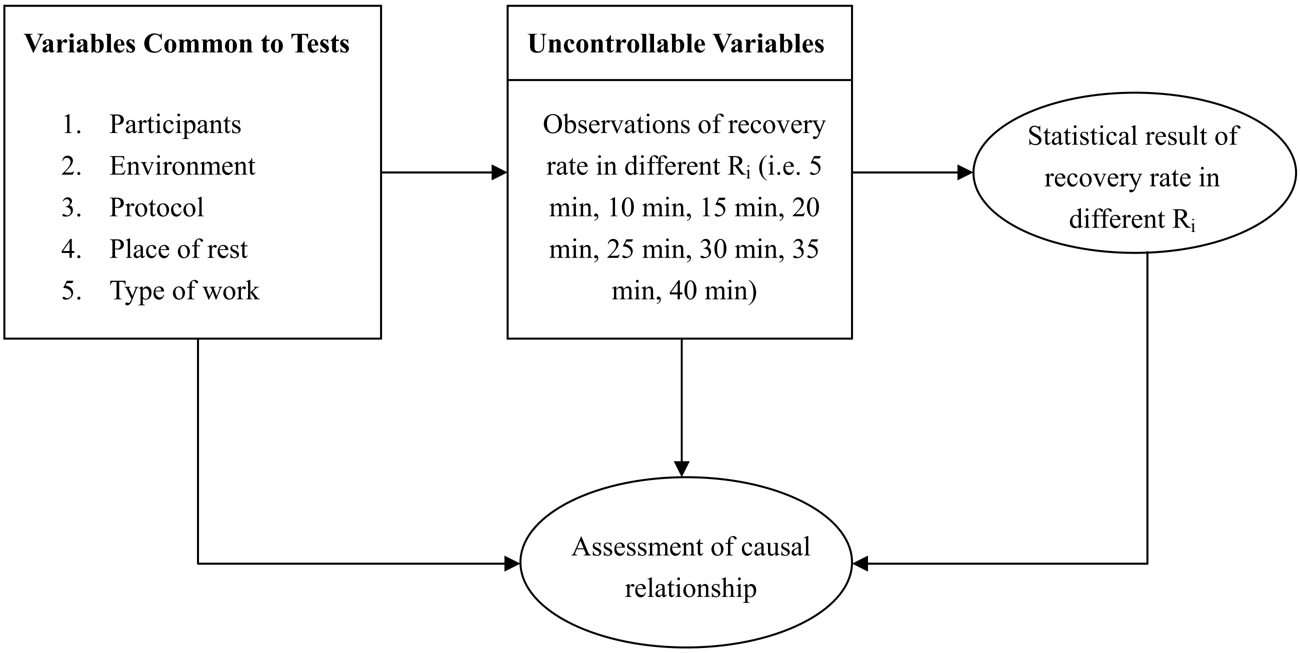

Figure 5

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Figure 5 Average scores indicating respondents' level of agreement in research stage II