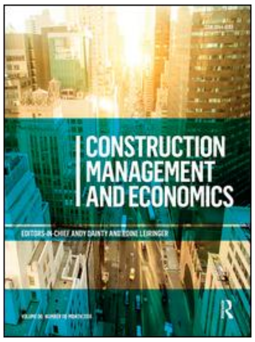

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Construction management and economics: the epistemology of a multidisciplinary design science

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Research in the field of construction management and economics (CME) can be characterized as a multidisciplinary design science. Results from the sciences and humanities are necessary inputs for this field of research that deals with design, production and operation of the built environment. The output of CME research as multidisciplinary design science consists of three types of solution concepts: empirical generalizations based on statistical data analysis (*technological laws*), concepts that specify what to do, if a certain result is to be attained under given circumstances (*functional rules*), and insights in the interrelationship between design, production and operation of the built environment and social practice (*socio-technological understanding*). Scientific justification of these solution concepts is obtained through testing them in the specific context of the built environment.

Keywords: Epistemology, knowledge production, design science.

Introduction

In construction management and economics (CME) as a field of research, a large number of different topics are studied. Contributions to the CME research programme come from a range of different scientific disciplines, such as project management (planning issues), information technology (product modelling), operations research (simulation), institutional economics and law (contracting issues), accounting and finance (project costing and corporate finance), human resource management (labour and personnel issues), and strategy and organization (internationalization). In CME as a field of research, there is no single theory but numerous frameworks and concepts.

Because of the different theoretical underpinnings of CME research, it is not surprising that the middle of the 1990s saw an increase in the number of publications debating the status quo of CME as a scientific discipline. Within this debate, a major focus was placed on the methodological underpinnings of CME. Here, different groups of scientists can be distinguished. Certain researchers favour empirical methodologies and rigorous statistical analyses (Runeson, 1997; Kwong Wing *et al.*, 1998). Other scientists are in favour of an enlargement of the methodological base to integrate case studies, action research and other interpretive methods (Seymour and Rooke, 1995; Raftery *et al.*, 1997).

This discussion on methodological issues touches only part of the problem and should be widened to include the question as to how CME scientists perceive knowledge and the ways that knowledge can be generated in this field of study, the so-called *epistemological* question. Contributions to the CME research programme come from different scientific disciplines and so the resulting CME knowledge has a multidisciplinary character. The ultimate objective of this knowledge is to design solutions for complex and relevant problems in the specific context of design, production and operation of the built environment. Hence, CME research is besides an explaining science also a 'design science'. The epistemological characteristics of CME as a multidisciplinary design science, however, are less clear than those of the sciences. Therefore, the primary objective of this paper is to characterize CME research as a multidisciplinary design science by classifying different types of CME research output from the perspective of the design sciences.

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The outline of this paper is as follows. First, it is argued that knowledge generation in CME research has a multidisciplinary character and that the design sciences play an important role in this field of study. In the next section, the epistemological characteristics of this definition of CME research are elaborated on. Then, the focus is on the characteristics of the research output of CME as a multidisciplinary design science. Finally, concluding remarks are made.

CME and different modes of knowledge production

Knowledge generation in CME research is based on distinct 'ways of making knowledge' Griffiths (2004) and Romme (2003) delineate three 'ideal-typical modes of knowledge production': sciences, humanities and design.

The first ideal-typical mode of making knowledge is mainly associated with the natural sciences, but has also been influential within the social sciences. It is a mode that is oriented towards the discovery of explanations or theories which can be generalized (Griffiths, 2004). Based on these theories, events can be predicted. Applied to the field of management research, the sciences help to uncover 'laws' that determine the characteristics, functioning and outcomes of organized systems (Romme, 2003). Organizational phenomena are approached as empirical objects with descriptive properties. In this mode of knowledge production, the focus is on testing hypotheses derived from general theories. A theory states a causality between isolated dependent and independent variables. Hypotheses derived from these theories are tested. By studying the correlation and variance among the variables the results of the testing support the hypothesis or not. Compared to other modes of knowledge production, the sciences are characterized by a relatively high level of consensus about appropriate questions, methods and analytical frameworks.

The second ideal-typical mode of making knowledge is mainly associated with the humanities. Here the focus is on the interpretive understanding of phenomena, rather than on understanding based on generalizable explanations (Griffiths, 2004). A major assumption is that knowledge is narrative in nature (Romme, 2003). Knowledge arises from what actors think and say about the world. Research focuses on trying to understand and interpret human experience. The goal of appreciating complexity is given precedence over the goal of achieving generality (Romme, 2003). Compared to the first ideal-typical mode of knowledge production, this knowledge base is more marked by competing or conflicting conceptual frameworks. Knowledge advance is not progressive, and may even be cyclical in nature, with intellectual fashions coming and going.

In the so-called 'design sciences', elements of the sciences and humanities are combined. The mission of a design science is to develop knowledge that the professionals of the discipline in question can use to design solutions for their field problems (Van Aken, 2004). The typical research product in a design science is not a causal model (as in the sciences) but a *technological rule* (Bunge, 1967). Design research draws on 'design causality' to produce knowledge that is both actionable and open to validation. This type of knowledge is used in the applied or vocational fields. What primarily distinguishes these fields from others is that they are oriented not towards knowledge and understanding for their own sake, but towards the use of knowledge and understanding in tackling problems and meeting the needs of the client or other actors.

The mission to develop knowledge that professionals in a certain discipline (information systems, medical science) can use is in line with the work of classic authors in organization and management which provided prescriptive knowledge for certain organizational problems (see for example the 'scientific management' movement of Taylor (1911) and the 'administrative theory' of Fayol (1918, 1949)). The scientization of research in the field of organization and management, however, diminished the academic respectability of this type of knowledge (Van Aken, 2004). This development has resulted in a longstanding debate on the relevance of academic research in the field of management and organization. In the past decades, concerns about this lack of relevance have been discussed in leading journals as *Organization Science* (Daft and Lewin, 1990; Romme, 2003). *Administrative Science Quarterly* (Susman and Evered, 1978; Beyer and Trice, 1982), and the *Academy of Management Review* (Hambrick, 1984; Mowday, 1997).

More recently, design science has been introduced in leading journals as an approach to improve the relevance of academic management research (Romme, 2003, 2006; Van Aken, 2004). Simon (1996) argued that design sciences can be relevant for research in organization and management because

> everyone designs who devises courses of action aimed at changing existing situations into preferred ones. The intellectual activity that produces material artefacts is no different fundamentally from the one that prescribes remedies for a sick patient or the one that devises a new sales plan for a company or a social welfare policy for a state (Simon, 1996, p. 111).

Also in information systems research, design science is referred to as an important approach (March and Smith, 1995; Järvinen, 2007). Lindgren *et al.* (2004)

claimed in the *MIS Quarterly* that '(d)esign is central to information system discipline (Markus *et al.*, 2002; Hevner *et al.*, 2004), and the action research method … is particularly appropriate for the development of system design principles' (pp. 436–7).

For designing solutions to field problems, the results from the sciences and humanities are necessary inputs. This is also the case in CME research. Theories from different scientific disciplines seek to predict or explain phenomena which are related to the design, production and operation of the built environment. Hence, knowledge from different disciplines is an important input for predicting or explaining these phenomena. Therefore, knowledge generation in CME research has a multidisciplinary character and the design mode of knowledge production plays an important role in this field of study. This multidisciplinary and design character of CME research will be analysed more deeply in the next section.

Epistemological characteristics of CME

Research in CME is closely interwoven with activities related to the built environment. The results of the sciences and humanities are a necessary part of CME research: a significant part of scientific CME research aims at explaining and predicting phenomena which are relevant to design, production and operation of the built environment. The focus is on the development and justification of theories that explain and predict these phenomena. Scientific justification of these theories is obtained through testing them in this specific context. Based on these results, CME researchers produce knowledge that can be used in designing solutions to complex and relevant field problems. Students are trained to be professionals who are able to use knowledge to design specific solutions for specific CME problems. In producing such knowledge, methodologies from the sciences and the humanities need to be translated to the specific context of the built environment. Theories do not only serve to research but also to practice (Koskela, 2000). Following the typology of Koskela (ibid.) theories in the field of CME research provide the following additional functions:

- tools for analysing, designing and controlling production and operation of the built environment;
- a common language or framework for communication;
- a condensed piece of knowledge supporting learning;
- transferring innovative practices to other settings.

The objective of CME is broader than only providing explanations and understanding because of the design mode of knowledge production. In terms of Hevner *et al.* (2004), the goal of the sciences is truth, the goal of the design sciences is utility. In CME, truth and utility are inseparable. Truth informs design and utility informs theory. The epistemological consequences of CME as multidisciplinary design science can be analysed further by comparing design science to the sciences using a set of epistemological characteristics of knowledge as proposed by Vincenti (1990) and Ropohl (1997).

Vincenti (1990), Ropohl (1997) and Boon (2006) proposed using a set of epistemological characteristics of knowledge for analysing the distinction between knowledge from the natural sciences and technological knowledge. These characteristics are the *objective* of the epistemological activities, the *objects* of knowledge, the *characteristics of the results*, the *quality criteria*, and the *methodology*. The distinctions between the sciences and design science can be captured and ordered within these characteristics of epistemological activities. Along the lines of Ropohl's and Boon's analysis, the epistemology of CME research is addressed by comparing sciences to design science:

- One of the *objectives* of CME as part of the sciences is finding laws and regularities that explain phenomena as they occur in design, production and operation of the built environment. CME as a design science is also interested in laws and regularities useful to improve or optimize this design, production and operation.
- The *object* of CME as part of the sciences deals with phenomena only as far as they are relevant to the built environment. CME, furthermore, also considers the socio-technical and usage contexts when focusing on design, production and operation of the built environment.
- With regard to the *characteristics of the research output*, CME as part of the sciences produces hypotheses and theories, whereas CME as a design science also generates solution concepts and design rules. The *character* of CME knowledge is 'general' in the sense that it applies to all design, production and operation activities related to the built environment in general, but it may also be more 'local', as it also accounts for more specific conditions (e.g. the production of particular building objects of a particular type in a specific country).
- The *scientific quality criteria* or justification of the CME research output are epistemological norms relevant both for the sciences and for design knowledge: construct validity, internal validity,

external validity and reliability (Yin, 1990). Quality in CME research as a design science also means the practical success of a process tool or a technical or organizational solution and approval by the construction practice.

- The *methodology* of CME research may be both specific for the sciences and specific to design research. In any kind of scientific activity abstraction with respect to the objects under study is a common method. In the field of CME research as part of the sciences, general theoretical statements are tested in the specific context of the built environment. In CME as a design science, methods and models are also used to design and redesign objects and processes in this specific context.

The distinctions just mentioned demonstrate that both the sciences and design science are important parts of CME research. The characteristics of the results, the quality criteria and the research methods used in the sciences are well known. The epistemological consequences of CME research as a multidisciplinary design science for the characteristics of the research output of this field of study are less clear. Therefore, the remainder of this article will be used to elaborate more deeply on this issue.

Solution concepts as research output

According to Broens and De Vries (2003) the issue of technological knowledge is still virgin territory. Most of what has been published about the nature and classification of technological knowledge draws from historical studies. In particular, the series of case studies of the design of aircraft by Vincenti (1990) is frequently cited. Generally, two types of technological knowledge can be distinguished: knowledge that enables a designer to go through the process of designing and the collection of knowledge about functions, materials, manufacturing and non-technical aspects of a design (economic, social juridical, etc.). In other words, design is both a process (set of activities) and a product (artefact) (Hevner *et al.*, 2004).

Much of the work performed by researchers in CME also deals with the design of solution concepts for design, production and operation of the built environment. In design science, these solution concepts are also called technological rules (Bunge, 1967). A technological rule is defined by Bunge (1967, p. 132) as 'an instruction to perform a finite number of acts in a given order and with a given aim'. These rules can be 'employed to control, transform or create things or processes' (Bunge, 1976, p. 154). According to Van Aken (2004, p. 228) a technological rule is 'a chunk of general knowledge linking an intervention or artefact with an expected outcome or performance in a certain field of application'. 'General' in this definition means that it is not a specific solution for a specific situation, but a general solution for a type of problem. If a rule is 'field-tested' this means it is tested in its intended field of application. If it is 'grounded' this means that the reason why the intervention or artefact gives the desired result or performance is known. A technological rule follows the logic of 'if you want to achieve Y in situation Z, then perform action X'. The core of the rule is that X is a general solution concept for a type of field problem (Van Aken, 2004).

A technological rule can be seen as a design proposition (Romme, 2003), linking a certain intervention to a certain outcome, while an untested technological rule can be seen as a preliminary design proposition. Such a proposition shares important similarities with a hypothesis, which results from the sciences, and explains the behaviour of one or more dependent variables in terms of the behaviour of an independent one.

Several authors have proposed detailed taxonomies for classifying different types of solution concepts, design propositions or technological rules, e.g. Bunge (1966), Vincenti (1990), Mitcham (1994), March and Smith (1995), Ropohl (1997), De Vries (2003) and Boon (2006). In these classifications, various types of technological rules were introduced such as technological laws, theoretical tools, properties of materials, functional laws, structural laws, design criteria and technological know-how.

De Vries (2003), for example, has developed a taxonomy that is based on the idea that the design of artefacts has to take into account the dual nature of artefacts, namely their physical and their functional nature. That insight leads to four types of technological knowledge: physical nature knowledge, functional nature knowledge, knowledge between physical and functional nature and process knowledge (knowledge of the series of actions that is needed to make that artefact do what it should do).

In the framework of March and Smith (1995) major types of design science outputs are constructs, models, methods and instantiations. *Constructs* or concepts constitute a conceptualization used to describe problems within the domain and to specify their solutions. In design science, *models* represent situations as problem and solution statements. A *method* is a set of steps (an algorithm or guideline) used to perform a task. An *instantiation* is the realization of an artefact in its environment. Instantiations focus on the efficiency and effectiveness of an artefact and its impacts on the environment and its users.

Vincenti (1990) and Ropohl (1997) distinguish technological laws, functional rules, socio-technological understanding, structural rules and technical know-how. *Technological laws* are a kind of systematization of the theoretical knowledge used for solving design problems. A *functional rule* can be an act, or a sequence of acts, but can also be a process or system. *Socio-technical understanding* is defined as 'a systemic knowledge about the interrelationship between technical objects, the natural environment, and social practice' (Ropohl, 1997, p. 70). *Structural rules* concern the assembly and the interplay of the components of a building object. *Technical know-how* can be gained by practice only.

From a design science perspective, the models, methods and instantiations of the framework of March and Smith (1995) are most closely akin to the technological law, the functional law and the socio-technical understanding of Vincenti (1990) and Ropohl (1997). The two remaining categories of technological knowledge in the classification of Vincenti (1990) and Ropohl (1997) are *structural rules* and *technical know-how*. Structural rules are indispensable in construction engineering and design. Many of these rules originate in traditional and current experience only, such as the rules for reinforcing a framework construction, or the rules for dimensioning the tolerance of a ball bearing. Structural rules and technical know-how are extremely important in construction practice but not a common output of CME research.

Therefore, in order to identify different types of CME research output as a multidisciplinary *design science*, three basic categories are used: technological laws (related to models), functional rules (related to methods) and socio-technical understanding (related to instantiations). The results of a number of articles published in *Construction Management and Economics* can be categorized by using this classification. In the following three paragraphs, examples are given of such a classification.

Technological laws are defined as a kind of systematization of the theoretical knowledge used for solving design problems. In other words, a technological law is a transformation of one or a few natural laws with regard to the solution of a design problem. Frequently, this technological law is not derived from a scientific theory, but is just an empirical generalization. For instance, the laws of metal cutting in manufacturing engineering have been obtained from conducting a range of experiments. When a technological law succeeds in practice, it is epistemologically justified. For Ropohl, the technological law is the major research output for engineers. When focusing on studies published in the journal *Construction Management and Economics*, it can be concluded that in a number of articles certain results can be categorized as *technological laws*. The application of statistical methods as linear and non-linear regression, time series approaches, stochastic optimization and simulation results in empirical generalizations. These empirical generalizations result in models and approaches aiming to improve for example site selection (Pantouvakis and Manoliadis, 2008), cost estimation (Wang and Horner, 2007), project planning (Bonnal *et al.*, 2005), production scheduling (Zhang *et al.*, 2002; Benjaoran *et al.*, 2005), forecasts of construction demand (Goh and Teo, 2000), forecasting construction labour demand (Rosenfeld and Warszawki, 1993) and cash flow forecasting (Kaka and Price, 1993).

Furthermore, in the field of CME, technological laws and empirical generalizations might be transformed into *functional rules*. The functional rule or method can be an act, or a sequence of acts, but can also be a process or system. These rules may be stated as verbal instructions, diagrams, protocols or charts, serving as recipes which can be used successfully without being understood theoretically. It is a kind of user instruction connecting the solution concept with the field problem, including indications and contra-indications, i.e. knowledge about when to use the solution concept and when not to. In the journal *Construction Management and Economics*, a number of studies were published containing results that can be categorized as *functional rules*. These *rules* specify what to do, if a certain result is to be attained under given circumstances. These *rules* are decision support systems, indicators, expert systems, performance, evaluation, data and cost models aiming to improve selection procedures (Abu Dabous and Alkass, 2008), partnering performance (Yeung *et al.*, 2008), technology adoption (Goulding *et al.*, 2007), assessment of environmental protection (Cheung *et al.*, 2004), project costs' information (Perera and Imriyas, 2004), selection (Cheung *et al.*, 2002) and design processes (Austin *et al.*, 2000), performance of building products (Koo and Tiong, 1993), bidding management (Dawood, 1995), and materials management (Tavakoli and Kakalia, 1993).

Socio-technical understanding is defined by Ropohl (1997) as 'a systemic knowledge about the interrelationship between technical objects, the natural environment, and social practice' (p. 70). Examples of this type of knowledge include among other things systems engineering, value analysis and technology assessment. The integration of management and engineering in construction research provides *par excellence* a socio-technical understanding of the interrelationship between construction objects, the built environment and social practice. CME research that clarifies this interrelationship is for example adoption processes of new technologies in construction, the interface between users or clients and the design and engineering process, and the efficiency and effectiveness of design processes in construction. In the journal *Construction Management* *and Economics* a number of articles have been published providing insights in the interrelationship between construction processes and social practice. Examples are studies on supply and shortages of skills in construction (Agapiou *et al.*, 1995; Mackenzie *et al.*, 2000), building partnerships between clients and contractors (Bresnen and Marshall, 2000a, 2000b), gender issues (Fielden *et al.*, 2000), occurrence of accidents (Salminen, 1995), learning approaches (Knauseder *et al.*, 2007), use of power (Walker and Newcombe, 2000) and conflict management (Stipanowich, 1997).

The three types of output just presented categorize CME research from a *design science* perspective. Certain types of CME research that focus only on explanations of why things happen (research explaining why certain effects came about, i.e. why the models, methods and instantiations work) do possibly not fit within this classification. Therefore, three types of solution concepts can be identified in CME research as a design science: (1) technological laws; (2) functional rules; and (3) socio-technical understanding. These types of research output designate knowledge one can use to design a specific process to produce a certain desired outcome or performance in design, production and operation of the built environment.

Concluding remarks

It is argued that the results of the sciences and humanities are necessary input for the design sciences (see (1) in Figure 1). CME research as a multidisciplinary design science aims to produce multidisciplinary solution concepts that can be used in solving complex and relevant field problems in design, production and operation of the built environment. The design mode of knowledge production is the common ground on which research in construction and management can meet (see (2) in Figure 1).

The epistemological consequences of this type of CME research are less clear than those of the explanatory sciences. Therefore, insights into the epistemological consequences of CME research as a multidisciplinary design science in terms of characteristics of the research output were needed.

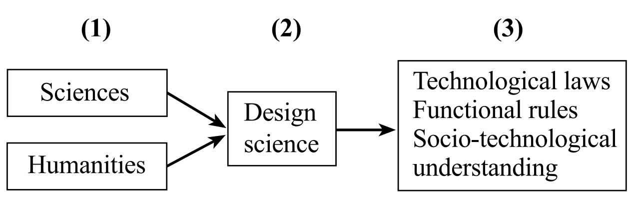

Figure 1 CME as field of research

It is concluded that the output of CME research as a multidisciplinary design science consists of three types of solution concepts (see (3) in Figure 1):

- technological laws: empirical generalizations based on statistical data analysis;
- functional rules: concepts that specify what to do, if a certain result is to be attained under given circumstances;
- socio-technological understanding: insights in the interrelationship between construction processes and social practice.

Justification of these solution concepts and approval by the construction practice is obtained through testing these concepts in the specific context of the built environment. By such testing, one tries to optimize or at least improve design, production and operation of the built environment—the ultimate aim of CME research.

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