Producing things or production flows? Ontological assumptions in the thinking of managers and professionals in construction

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Abstract

New approaches to production management can be conceptualized as treating production as flow rather than transformation. These alternatives can in turn be regarded as reflecting opposing ontological positions, holding respectively that reality is constituted of temporal process, or atemporal substance. The new production philosophy thus arguably represents a process ontology radically different from the atemporal metaphysics underlying conventional methods and theories. Moreover, research in physics education has identified the disjunction between ontological categories of 'substance' and 'process' as a particularly acute barrier to understanding process phenomena. Studies are presented which demonstrate the possibility of specifying and classifying mental models, with regard to two important management solutions in construction. Thus, procedures typically adopted in Quantity Surveying and the implementation of Structural Engineering Design are examined. Methods of measurement used in Quantity Surveying are designed to account primarily for physical, rather than temporal properties. In design, the emphasis is on representing properties of finished structures, rather than the construction processes. The process is then managed by treating the design and its execution as separate products. It is argued here that alternative, more effective management solutions are derived from a process ontology.

Keywords: Decision making, Indexicality, Learning, Lean construction, Management theory, Metaphysics, Ontological categories.

Introduction

This paper addresses the problem of organisational change in the construction industry by asking some fundamental questions about the way we think. It builds on the argument outlined in an earlier paper (Koskela & Kagioglou 2005) that since the pre-Socratic period of philosophy, there have been two basic metaphysical views. One view holds that the world consists of substances or things. The other, that the world consists of processes, that is, intrinsically temporal phenomena. These metaphysical assumptions influence how the subject of an inquiry or action is conceptualized. The thing-oriented view tends to lead to a a-historical approach, the requirement or assumption of certainty and analytical decomposition. The process-oriented view favours a historical and contextual approach, the acknowledgement of uncertainty and a holistic orientation.

It is arguable that production is intrinsically a process oriented endeavour. That is to say, it is better conceived of as a movement through time, than as an object. However, Koskela & Kagioglou argue that until recently, a substance oriented view of the world has dominated research and practice in production management. In this view, innovations originating in post-war Japan are seen to be based on a re-conceptualization of production as a flow of materials and activities rather than as transformation of substance (Koskela 1992, 2000). This raises the possibility that the innovations depend upon the application of radically different ontological categories than those currently dominant in the West. Conversely, the hypothesis arises that a mismatch between the assumed nature and true nature of production has led to major generic failures of production management. Below, we explore this idea with reference to the nature of ontological categories and the role they play as facilitators of innovation, objectives of educational achievement, and impediments to change.

Thus, the paper explores the origins of ontology in Ancient Greek thought, and shows its significance to recent innovations in construction management and , education research into the teaching of physics and other natural sciences (Chi 2005). It then seeks to demonstrate the viability of analysing construction management solutions to determine their ontological basis and categorising them accordingly. It also initiates an investigation of the relevance of such categories to the effectiveness of such solutions. Two ethnographic studies are employed to achieve these latter aims. These cases explore formal methods of reasoning which focus on objects, rather than processes as the key to understanding and communicating about construction projects. In the case of the measurement study, this involves pricing quantities rather than activities. In the case of the design study, it consists of treating design and construction as separate products (finished drawings and finished buildings) rather than two aspects of a continuous iterative process.

Process and Substance Ontologies

In this section, we reiterate the argument first proposed in Koskela & Kagioglou (2005). They point out that substance based metaphysics has a history dating back to Aristotle, whose influence on mediaeval philosophy laid the basis for the dominance of a substance ontology in modern times. Newton, and the Enlightenment movement greatly promoted this way of viewing the world. Classical mechanics deals predominantly with things and substances and as physics was taken as a model for other sciences, substance based metaphysics became further entrenched as the dominant view.

Following from substance metaphysics, the method of analytic decomposition promoted by Plato and Descartes, among others, implies that the main direction of research and problem solving in general should be an investigation of ever smaller parts of the whole, searching for explanations at the lowest possible level. The success of science since Newton has proved this to be a powerful method.

The first major proponent of process metaphysics is generally identified as Heraclites, who held that "everything flows". Philosophers and scientists such as Leibniz and Hegel continued to be inspired by this view, even while substance metaphysics dominated. However, a decisive push towards process metaphysics was given by the development of relativity theory and quantum theory. In a similar way to the situation following Newton's new physical theories, sciences other than physics have begun to orient themselves according to the newest findings of physics, drifting thus towards a process metaphysics. We have, for instance, the emergence of complexity science. Overall, substance metaphysics remains dominant, despite the growing influence of process metaphysics.

According to contemporary understanding of process metaphysics (Rescher 2000),

- time and change are among the principal categories of metaphysical understanding,
- processes are more fundamental than things for the purposes of ontological theory,
- contingency, emergence, novelty and creativity are fundamental categories of metaphysics.

Thus, process metaphysics directs attention to the context, the larger process of which a unit of consideration is part. It also suggests that phenomena are not necessarily universal, but specific to a particular time and place. The common feature of both these implications is that time is elevated to a major position in the scheme of relevance.

The Significance of Ontological Categories

In this section we identify two strands of research, in production management and cognitive science respectively, which make use of these metaphysical positions.

Historical analysis points to three different conceptualizations of production that have been used in practice and conceptually advanced in the 20th century (Koskela 2000). In the first conceptualization, production is viewed as a transformation of inputs to outputs. Production management equates to decomposing the total transformation into elementary transformations, tasks, and carrying out the tasks as efficiently as possible. The second conceptualization views production as a flow, where, in addition to transformation, there are waiting, inspection and moving stages. Production management equates to minimizing the share of non-transformation stages of the production flow (often called waste), especially by reducing variability. The third conceptualization views production as a means for the fulfilment of the customer needs, i.e. as value generation. Production management equates to translating these needs accurately into a design solution and then producing products that conform to the specified design. Koskela (2000) argues that all these conceptualizations are necessary, and they should be utilized simultaneously.

Koskela & Kagioglou (2005) argue that the transformation model is based on substance metaphysics, whereas the flow model, in focusing on temporal developments, and the value generation model, in focusing on the evolutionary emergence of product realization, subscribe to a process oriented metaphysics.

Koskela (1992) suggests that the emergence of lean production represents a switch from viewing production solely as transformation to conceiving production predominantly as flow, even if the value generation and transformation models are also recognized and utilized. This same theoretical shift is behind 'Lean Construction', a term coined in the framework of the establishment of the International Group for Lean Construction in 1993. It refers to a theory-based movement towards better practices in construction, inspired by the Toyota Production System and its implementation in other companies. However, due to the unique features of the construction industry, Lean Construction requires a partially different set of principles, methods and tools in comparison to lean car production.

The Last Planner™ system[1] (LPS) of production control (Ballard & Howell 1998; Ballard 2000) is

[1]The trademarking of the LPS is intended to prevent abuse of the system and not to restrict its use. The Lean

one such tool, developed specifically for the production situation on construction sites. A fruitful object for theoretical interpretation and refinement, integrating the transformation and flow perspectives (Koskela 1999), it is geared towards reducing variability (unpredictability) of the flows of production, particularly contributing to the minimization of a type of waste typical in construction, that of making-do (Koskela 2004). Crucially, it addresses the unpredictable, non-iterative aspects of a construction project by focusing on the short term planning and control of operations.

Prior to these developments, the significance of ontological commitments for human thinking and learning had been addressed in cognitive science (*viz* Chi 1992; Chi & Roscoe 2002; Chi, Slotta, & de Leeuw 1994; Itza-Ortiz, Rebello & Zollman 2003). Chi advances the view that there are three major ontological categories or schemas for the human mind: matter (equating to substance as used earlier in this paper), processes and mental states (Chi et al. 1994). In various fields it has been observed that there is a natural preference for matter-based conceptualizations. Also it has been observed that existing knowledge, often matter-based, sometimes prevents the learning of new information. Students apparently have fundamental difficulties in absorbing process based theories, in contrast to more easily understood substance based theories (Itza-Ortiz, Rebello & Zollman 2003). Complicated, abstract and dynamic concepts are particularly difficult to learn, because there is an incommensurability between the categorical structure or schema to which students attempt to assimilate these concepts and the veridical (i.e. coinciding with realities) structure or schema to which they ought to assimilate them (Chi 2000). The shift to a new schema is not itself inherently difficult, but it is challenging when students lack awareness of their misconceptions or when they lack the alternative schemas to which they should shift (Chi & Roscoe 2002). One common type of incommensurability arises when entities belonging to the process scheme (examples from natural sciences: electrical current, diffusion, evolution) are approached through schemes belonging to the matter scheme (Chi 1992 pp140-141): "for students to really understand what forces, light, heat,

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Constreuction Instute which holds the trademark rights freely permits use of the system internally by organisations.

and current are, they need to change their conception that these entities are substances, and conceive of them as a kind of constraint-based event”.

Methodology

The intention to seek evidence of substance thinking in the construction industry presents a series of methodological problems: the visibility of ontological categories for the purpose of research; the need to guard against selective bias in categorising data; and the extent to which successfully categorised data can then be used as a basis for generalisation. The strategy adopted to overcome these difficulties is to present ethnographic (Schwartzman 1993, Hammersley & Atkinson 1994) and auto-ethnographic or armchair (Hockey & Collinson 2006, Francis & Hester 2004) case studies which conform to the weak form of the unique adequacy (UA) requirement of methods. This form of the requirement demands that the researcher acquires practical competence in the research setting, such that they are capable of performing the activities reported (Garfinkel & Wieder 1992; Garfinkel 2002; Rooke & Seymour 2005). A particularly clear demonstration of conformance to the UA requirement is possible where an auto-ethnographic technique is used, as this involves the researcher in reporting on their own practice.

The UA requirement assumes that the thought processes involved in the constitution of the cases are fully available to the researcher as practical reasoning activities. In contrast, the cognitive theory which underlies educational psychology suggests that ontological assumptions, like other mental phenomena, are essentially hidden processes. Of course, from a cognitivist perspective, such processes are still detectable, or they could not be discussed at all. From this point of view, it is the behavioural manifestation of the mental process that presents itself to the researcher as an observable object of research, allowing access to the concepts employed. However, a formulation more readily compatible with UA is derived from the philosophy of Wittgenstein and Ryle; this rejects the notion of a hidden mental process intervening between physical brain function and meaningful activity (Wittgenstein 1958, Ryle 1963; Button, Coulter, Lee & Sharrock 1995). Thus, to know how someone performs an analysis in practice, is identical to knowing the thought processes involved. This can perhaps be seen most clearly in the auto-ethnographic example in 'Measurement' study. Here, the reader is instructed in the procedure required to make up part of a Bill of Quantities using the Civil Engineering Standard Method of Measurement (CESMM). This part of the report, when considered in isolation, also fulfils the strong unique adequacy requirement, in that it consists only in the practical analysis used to constitute the phenomenon, that is to say, the method of measurement reported (Garfinkel & Wieder 1992; Rooke & Seymour 2005). This indigenous analysis is thus rendered as 'instructed action' (Garfinkel 2002). While the 'Design' study does not take such an explicit instructional form, it nevertheless explicates reasoning processes which are found in the research setting, such as the distinction between design defects and construction defects and the consequent contractually determined attribution of blame.

Nonetheless, the reasoning processes made visible through the case studies cannot be said to constitute in themselves ontological assumptions. The latter must somehow be shown to characterise, underlie, or be inherent in these processes. Since such a reasoning process is not evident in the activities reported, its introduction here precludes the use made of the ethnographic data from meeting the strong form of UA (Garfinkel & Wieder 1992; Garfinkel 2002; Rooke & Seymour 2005). Thus, the further problem arises of vindicating such attribution in any particular case. The research question may be phrased as a problem of categorisation: 'should this phenomenon properly be categorised as representing a thing ontology, or conversely, should it be categorised as representing a flow ontology'? Thus, the procedure is analogous to the process of axial coding in grounded theorising (Glaser 1992; Glaser & Strauss 1967; Strauss & Corbin 1998). The operational definition used for classification purposes is shown in Table 1.

This leaves the question of the extent to which we can generalise from the data. Clearly, the *a priori* nature of the theoretical categories used and the retrospective use of previously collected data preclude a grounded theory approach to generalisation. The procedure adopted here is closer to the form of analytic generalisation recommended by Yin in which “previously developed theory is used as a template with which to compare the empirical results of the case study” (Yin 2003 pp. 32-33). Thus, the data is examined through a theoretical lens, in order to establish commonalities across cases.

In addition, the case studies, to be discussed next, have been selected from a range of possible cases because they represent common practices relating to important processes in construction management. The use of a bill of quantities for pricing work is both traditional and very widespread, as are the methods of specification and contractual allocation of responsibility discussed in the 'Design' study.

Case Study: Measurement

Construction and civil engineering contracts in the UK traditionally use bills of quantities as a means of determining the price of work. According to the Institute of Civil Engineers (ICE):

> "The objects of the Bill of Quantities are:
>
> - a. to provide such information of the quantities of work as to enable tenders to be prepared efficiently and accurately
> - b. when a contract has been entered into, to provide for use of the priced Bill of Quantities in the valuation of work executed." (Institute of Civil Engineers 2005)

Bills of Quantity (BoQ) are based in turn on a method of measurement. While methods differ, they share certain assumptions that are arguably founded in a substance ontology.

According to the ICE, the object of the Civil Engineering Standard Method of Measurement (CESSM) is "to set forth the procedure according to which the Bill of Quantities shall be prepared and priced and the quantities of work expressed and measured" (*ibid.* 2005).

Thus, for instance, under this method of measurementClass F specifies how the provision and placing of in situ concrete should be measured (see Table 2). For each element of the class, specific analytic moves are stated which constitute categorizations or measurements which, when applied to the [drawings], render a quantity that may then be priced. Thus for instance, to price the placing of of a concrete structure, it must first be determined whether the concrete type is to be mass, reinforced or pre-stressed. Then the type of concrete feature is determined, according to its structural function. Finally, a dimensional measurement is specified. (Institute of Civil Engineers 1991)

Thus, the explicit analysis involved in pricing the placing of the concrete is concerned with the physical properties of the concrete. Of course, this does not mean that the actual activity of placing the concrete is ignored by the contractor when determining price. The final rates for the quantities include elements for plant andlabour as well as indirect costs (Jennings 1995). What it does mean is that these other elements are reduced to ancillary properties of the quantities of material priced and *are not available for subsequent discussion between parties to the contract*.

Furthermore, as Rooke, Seymour & Fellows (2004) have pointed out, these costing practicescan provide one of the bases for claims planning, in which a difference between the tender price and out-turn price is generated. In these cases, a tempora method of pricing is employed which makes the following assumptions in addition to those contained in the substance based method of measurement, that: (a) the quantities seen to be required will change over time due to mistakes in the tender documents, design changes and unforeseen contingencies on site; (b) the sequential temporal relationships between tasks will prove problematic. What Rooke *et al* do not make explicit is that the anticipation of such changes relies upon an attention to process that goes well beyond the substance oriented structural concerns upon which methods of measurement are based. Thus, for instance, while the quantity, type and final form of concrete is formally accounted for in the method of measurement, the distance that the concrete must travel from the concrete plant and the route it must take are not.

Critiquing the conventional approach to costing, Hoare and Broome (2001) argue that BoQ based on CESMM are preferable to those using other standard methods of measurement, as they allow method related charges to be included as General Items. Nevertheless, they note two remaining problems with CESMM based bills. First, "the aggregation of the BoQ items into self contained construction operations is done by those representing the client and may not correspond with how the contractor will actually construct the works" (Hoare & Broome 2001, p. 20). Second, the way prices are made up is not transparent as to the contractor's mark up, or assumptions about efficiency. Hoare and Broome advocate replacing the bill of quantities altogether, with an activity schedule such as that included in the Engineering and Construction Contract package (Institute of Civil Engineers 1998). This method of pricing uses tasks rather than quantities as the basic unit of measurement and allows the price to be more closely related to the actual process of construction.

Case Study: Design

Since civil engineering and architectural drawings describe finished products which are physical objects, substance ontology might at first appear to provide them with an adequate basis in reality. However, substance metaphysics directs attention away from the process by which such product descriptions are implemented through activity on the construction site . Thus, the planning and control of the construction process also resonates a substance ontology which is reflected in contractual arrangements. In this contractual specification of the management process, the design and the implementation of the design are treated as separate products, rather than iterative phases in the same process loop. This contributes to a conflict-prone interface between the two phases.

The problem is evident in a study of the achievement of design-specified depths of cover for steel reinforcement in concrete structures. It was found that the cover achieved in a sample of walls and columns on twenty-five construction projects, all being undertaken by quality assured contractors, showed significant variation from values specified in the design (Shammas-Toma, Seymour & Clark 1996). Design practice for specifying required cover is based on codes of practice which assume that there are consistent patterns in the variability of cover achieved in the finished product, where, in other words, the yet-to-be finished product on site provides the standards for assessing the functionality of the design, ignoring the process by which the product will be realised. The assumption is problematic because structural elements differ in type, shape, size, design complexity and location. However, even when constructing identical elements, there was found to be substantial variation in the consistency of the processes involved. Statistical analysis of variability, stated by Juran and Gryna (1993) as a necessary criterion for the use of constant tolerances as an effective quality standard, were found to be non-existent on the study sites (Shammas-Toma, Seymour & Clark 1996).

The dimensional variability of the outcomes of construction processes are recognised to an extent in BS 5606, which provides a formula for site personnel to calculate the consequences for the achievement of specified tolerances. It is also true that designers will make adjustments in their specifications to code recommendations if they anticipate circumstances on site that will make strict adherence to the code difficult or impossible. However, designers are usually almost entirely ignorant of the production conditions in which their designs will be implemented. In practice, responsibility commonly devolves to the site engineer, who can exercise discretion in applying the specifications. This effectively leaves the precise execution of design subject to the multiple vagaries of inter-personal relations on site, in a context where contractual penalties for departing from the design can always be mobilised, however unrealistic or inappropriate the specification might be (Seymour, Shammas-Toma & Clark 1997).

The allocation of such penalties relies on conventionally understood and tacitly accepted reasons for such variation which derives from the assumption, *written into contractual arrangements*, that it is possible to distinguish design defects and construction defects (Fraczek 1979). The former are seen to originate in the design office and result in design that is physically impossible to execute or to which subsequent structural failure can be traced. ‘Construction defects’ includes all other defects, the result of, for example, ‘site inefficiency’, ‘poor workmanship’, ‘poor supervision’ and ‘inadequate controls’, which contractually cannot be laid at the door of the designers.

This allocation of responsibility follows directly from treating design and implementation as two distinct entities. Seymour *et al* offer a contrasting, process based analysis, intended to facilitate improvement rather than allocate penalties.

Discussion

If recent innovations in production management such as the Toyota Production System and the emergence of the Lean Construction movement do indeed represent an ontological shift from a metaphysics of substance to a metaphysics of flow, and if Chi and her colleagues are correct in identifying allegiance to ontological categories which are inappropriate to the task at hand as a major obstacle to learning, this poses a significant challenge to the construction industry.

The two case studies presented here seem to point in that direction. In terms of the operational definition specified above, the 'Measurement' study shows how: a standard method of measurement is based on the assumption that its categories will be applicable across all construction projects; it is further assumed that the placing of any quantity of concrete will cost the same as any similar quantity in the same category and that this cost can be determined in advance. Thus, the categories used in the method are intended as universal abstractions which can be used to specify future events regardless of changing context. More generally, it has been shown that the logic of the method of measurement is based primarily on the physical properties of the substance which is being placed, rather than the process of placing it. Similarly, the 'Design' study shows how universal standards for specifying design tolerances are expected to override the contingencies of the construction process. Notwithstanding the unpredictable nature of this process, design specifications are contractually expected to determine the realisation of the finished product, regardless of the context of that realisation.

In contrast to these substance based procedures, three others were noted: the LPS; the practice of claims planning; the ECC Activity Schedule. The starting point for the development of the LPS was the observation that typically only half of the tasks in a weekly plan get realized as planned on site (Ballard & Howell 1998). By thus placing the unpredictability of the construction process at the centre of the analysis, the LPS addresses the need to recognise continually changing context thorough the short term planning and control of operations. The goal is to ensure, through different procedures and tools that: (a) all the necessary preconditions of a task exist when it is started, such that the task can be executed without disturbances; (b) it is in fact completed according to the plan; or (c) reasons for failure to complete are established, recorded and fed into future planning as well as into continuous improvement of the construction process. The proportion of tasks completed as planned is monitored on a weekly basis, as a measure of the effectiveness of planning. Using rolling look-ahead planning, the preconditions for tasks are provided for the following 4-6 weeks, thus maintaining a sufficient backlog of ready tasks. In the framework of the flow view, it is geared towards reducing variability, particularly contributing to the minimization of a type of waste typical in construction, that of making-do (Koskela 2004).

Claims planning (Rooke, Seymour & Fellows 2004) is another procedure that appears to have an ontological basis in process metaphysics. The Engineering and Construction Contract (Institute of Civil Engineers 1998) contains an attempt to reform costing practices which would also appear to owe something to a process ontology. The contract's use of an activity schedule as a pricing and payment mechanism shifts the focus from quantities to activities.However, it is necessary to be cautious about categorising the activity schedule in this way, as the contract is dependent on project planning methods which seem to owe more to a substance metaphysics. Thus, a central role is given to a method of task decomposition that is intended to determine the course of activity in advance, neglecting the issues of contingency and context raised above.

As noted above, the two ethnographic cases presented here, were selected as examples of key methods of managing the construction process. They do not represent the results of a systematic search through the available data for all identifiable examples of process and substance thinking. They are two, out of a number of cases, that presented themselves to us as clear examples of widespread management practices which fitted our conception of substance based thinking. Similarly, a number of examples of process based solutions have presented themselves to us as relevant. Of those cited here: Last Planner derives from the process based Lean Production movement; the Activity Schedule from another initiative for industry reform, the Engineering and Construction Contract (NEC).

However, claims planning falls into an entirely different category. Rather than an attempt to reform construction industry practices, claims planning seeks to adapt to substance based practices and to exploit them. Thus, unlike Last Planner, or theNEC, claims planning can thrive only to the extent that substance based solutions exist to be exploited. The practice of claims planning then, while dependent upon process based reasoning, nevertheless constitutes further evidence for the prevalence of substance based solutions.

Ultimately, the question of the distribution of these alternative modes of thought and their adequacy in the full variety of situations in which they are employed must be left for a more systematic study.

It was stated at the outset that the methods to be examined were integral to the operation of the construction process: it is also the case that they are at the root of many of its troubles. Thus, it is not only true that estimating procedures follow a logic that privileges substantial over temporal qualities, they are also open to subversion by the more temporally based analysis of claims planning.

Similarly, the concrete cover studies show how the treatment of design as a product, rather than a process in iterative communication with that of construction, leads to problems in the maintenance of quality. The inability of the designer to predict the conditions under which the design 'product' will be executed reduces the possibility that drawings will be entirely adequate to their purpose. Meanwhile, the contractual role of such drawings, in specifying a further product, contributes to an air of unreality and antagonism on site (Shammas-Toma, Seymour & Clark 1996).

Conclusion

If our argument is correct, then an over-reliance on the ontological category of substance poses a significant conceptual barrier to progress in the construction industry. This assertion is founded on four assumptions. First, that production management solutions can be clearly distinguished as to their ontological basis; our case studiesand discussion demonstrate how such a distinction is possible. We have identified two methods based on object metaphysics (CESSM and the design/construction dichotomy)and three examples of flow metaphysics (the Activity Schedule, the LPS and claims planning). Second, that substance based solutions predominate in the construction industry. We have shown that this is the case regarding two important methods used in construction management in the UK, it remains for the analysis to be extended to cover a wider range of management solutions. Third, that the most successful production management solutions are flow based. While there is a substantial and growing body of theoretical work to vindicate this, it remains to be demonstrated empirically. Finally, that adherence to substance thinking presents a barrier to learning flow based solutions. Again, this is strongly suggested by the work we have cited in educational psychology, but remains to be demonstrated empirically in the construction industry.

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