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SEEKING EVIDENCE FOR THE ROLE OF ONTOLOGICAL ASSUMPTIONS IN THE THINKING OF MANAGERS AND PROFESSIONALS

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Abstract

Shingo's (1988) seminal innovation in the theory of production management can be seen as a re-conceptualization of production as flow rather than transformation (Koskela 1992). These alternatives can in turn be regarded as reflections of opposing ontological positions which have dominated Western philosophy, holding respectively that reality is constituted of either temporal process, or atemporal substance (Roochnik 2004). Koskela & Kagioglou (2005) suggest that lean production philosophy is based in a process ontology, radically different from the atemporal metaphysics underlying conventional methods and theories.

Chi (1992) has argued that the disjunction between ontological categories such as 'substance' and 'process' can constitute a particularly acute barrier to understanding.

Studies such as Itza-Ortiz, Rebello & Zollman (2003) have demonstrated the possibility of specifying and classifying learners' mental models as an aid to learning.

We examine procedures typically adopted in Quantity Surveying, Structural Engineering Design and Project Planning, in order to specify the mental models involved. We find evidence of an underlying substance ontology. Methods of measurement used in Quantity Surveying are designed to account for physical, rather than temporal properties. In design, the emphasis is on representing the properties of the finished structure, rather than the processes by which it is constructed. More subtly, the temporal dimensions of the construction process are represented in project planning as 'lumps' of time, thus ignoring important facets of their nature as events. We conclude that attention to the role of ontological categories in industry thinking will facilitate the teaching of process oriented approaches to construction project management.

Keywords: Construction Process; Lean Construction; Ontological Categories; Production Theory; Project Management.

1. Introduction – A New Way of Thinking for Construction?

Since the pre-Socratic period of philosophy, there have been two basic metaphysical views. One holds that there are substances or things, that is, atemporal entities in the world. The other insists that there are processes, that is intrinsically temporal phenomena. These metaphysical assumptions tend to strongly influence how the subject of the inquiry or action is conceptualized. The thing-oriented view seems to lead to analytical decomposition, the requirement or assumption of certainty and an a-historical approach. The process-oriented view is related to a holistic orientation, acknowledgement of uncertainty and to an historical and contextual approach.

It can be argued that production is intrinsically a process oriented endeavour. However, an analysis of current conceptualizations and methods has led Koskela & Kagioglou (2005) to conclude that until recently, a substance oriented view of the world has long dominated research and practice in production management. In contrast, 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.

Meanwhile, education research into the teaching of physics and other natural sciences has identified obstacles to the learning of process-based theory (Chi 2005). Students apparently have fundamental difficulties in absorbing process based theories, in contrast to more easily understood substance based theories (Itza-Ortiz, Rebello & Zollman 2003).

Thus, we may hypothesize that: (1) both academics and practitioners have conceived substance-based understandings of construction management issues; (2) these have resulted in the implementation of a methodology that is in some respects counter-productive; (3) whereas the correctives suggested have primarily been process-based; (4) but their implementation has not succeeded because they have been

misunderstood. If it can be proven that these hypotheses are valid, radically new prospects for teaching and implementing process-based managerial approaches in construction will be opened up. Initiatives similar to those in physics education, involving explicit ontology training and appropriate information technology support, could be introduced to help overcome these conceptual barriers.

In this paper we address all four of these hypotheses by examining a body of ethnographic work in the construction industry and focusing on aspects of three key features of construction management practice: measurement; design; and programming.

Ethnography is an approach to research in which techniques including direct observation and semi-structured interviewing are employed simultaneously with data analysis to achieve an account of a research setting from the point of view of a member of that setting (Schwartzman 1993, Hammersley & Atkinson 1994). The use of such findings here, is to test the hypotheses by comparing a theoretical analysis with an analysis that is native to the settings under examination.

The original ethnographic research from which our data is drawn was conducted according to the requirement of unique adequacy (Garfinkel & Weider 1992, Garfinkel 2002). That is to say, the researcher must (1) achieve an everyday competence in the practices reported and (2) refrain from imposing upon the data an analysis that originates from outside the setting under study (Rooke & Seymour 2005, Rooke & Clark 2005). However, in making the comparisons necessary for testing the hypotheses, the second part of the requirement has been somewhat relaxed. Thus, the data conforms fully only to the weak requirement of unique adequacy (Garfinkel & Weider 1992). It is intended to: (1) illustrate various methods used by professionals and managers in order to organize the work of construction; (2) to establish the viability of using the concept of 'substance ontology' to account for these methods.

The account of measurement given in section four of this paper is based on a reading of standard texts used by professionals and instruction by an estimator as to how such texts are used in practice to price work. It is not suggested that this formal procedure fully accounts for estimating practices in construction; additional, informal methods

are also employed, which are often the basis of 'contractual games', such as those documented by Rooke, Seymour & Fellows (2004).

Section five on design, revisits a previously reported study (Seymour, Shamma-Toma, & Clark 1997; Shamma-Toma, Seymour, & Clark 1996; Shamma-Toma, Seymour, & Clark 1998) to re-analyse those findings using the substance/flow dichotomy.

Finally in section six, fieldwork on a small highways project is presented, in order to examine the assumptions underlying the programming of work and the difficulties to which these can lead. For this study, the researcher attended monthly site meetings and interviewed participants (Rooke 2001).

These examples have been selected from a range of possible cases because they represent key features of the production process, involving cost, quality and time. The methods examined are thus integral to the planning and execution of construction projects.

2. Lean Construction

As the issues discussed have their origin in Lean Construction, it is opportune to present its background and central ideas here. The term Lean Construction was 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, often also called lean production.

What, then, is the theoretical basis of Lean Construction? 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 argues that all these conceptualizations are necessary, and they should be utilized simultaneously.

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 also behind Lean Construction. However, due to a different context, Lean Construction requires a partially different set of principles, methods and tools in comparison to lean production.

Last PlannerTM is the most central new tool developed specifically for production situation on construction sites (even though trademarked by the Lean Construction Institute, it is permitted for the method to be used internally by an organization without constraints). The starting point for this was Ballard's observation that typically only half of the tasks in a weekly plan get realized as planned on site (Ballard & Howell 1998). In a series of experimental work, a new approach to production control, called the Last PlannerTM System (LPS), was developed (Ballard 2000). LPS has provided a fruitful object for theoretical interpretation and refinement, integrating the transformation and flow perspectives (Koskela 1999). 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).

LPS addresses 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. 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.

3. Process and Substance Ontologies

Koskela & Kagioglou (2005) have argued 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. Substance metaphysics has a history dating back at least as far as Aristotle, who says in his treatise on metaphysics (Gamma 2): "...the fundamental duty of the philosopher: it is to gain possession of the principles and causes of substances." Even if Aristotle was not the first to take such a view, it was due to his huge influence up to the Middle Ages that a substance ontology came to dominate. The next push towards this stand came from Newton, and the whole movement of Enlightenment. Classical mechanics, as developed by Newton, dealt with things and substances, and as physics was taken as a model for other sciences, substance based metaphysics tacitly gained an even greater dominance.

What follows then from substance metaphysics? An idea intimately related to substance metaphysics is decomposition. Promoted by Plato and Descartes, among others, this implies that the main direction of research and problem solving in general is an investigation into ever smaller parts of the whole, searching for explanations at the lowest possible level. Of course, the success of science since Newton proves that this is a powerful method.

The first major proponent of process metaphysics was Heraclites, who held that "everything flows". Heraclites' thinking continued to inspire philosophers and scientists such as Leibniz and Hegel even during the dominance of substance metaphysics. 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 (thus for example, complexity science). The movement of post-modernism has also been argued to be ultimately based on process metaphysics (Chia 2002).

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.

The basic direction of research, in the spirit of process metaphysics, is to look for the context, the larger process of which the unit of consideration is part, and to search for explanation at that level. A related consideration is that phenomena are not necessarily universal, but rather attached to a specific time and place. The common feature to both issues is that time is elevated to a major position in the scheme of explanation.

The significance of these ontological commitments for human thinking and learning has recently been addressed in cognitive science. 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 learning new information. 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 in press). 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, 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”.

4. Measurement

Construction and civil engineering contracts 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 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 measurement Class F specifies how the provision and placing of in situ concrete should be measured (see fig 1). 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 prestressed. 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 and labour 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 practices lead to adverse consequences for the construction client when an 'unofficial' temporal approach to costing is taken by the contractor, thus creating a gap between tender price and outcome price. Thus, temporal pricing makes the following additional assumptions, that: (a) the quantities seen to be required will change over time due to mistakes in the tender documents 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 often relies upon an attention to process that goes well beyond the 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 is not.

Class F. 1-4, provision of in situ concrete	
FIRST DIVISION	Specify whether the mix is standard, designed, or prescribed.
SECOND DIVISION	for provision of standard or designed mixes, state strength; for provision of prescribed mix, state proportions of each constituent
THIRD DIVISION	type of cement and nominal maximum size of aggregate
Class F.5-7, placing of in situ concrete	
DIVISION ONE	mass, reinforced or prestressed
DIVISION TWO	(1) blinding; (2) bases etc.; (3) suspended slabs; (4) walls; (5) columns and piers; (6) beams; (7) casing; (8) other
DIVISION THREE	(* .1-4) state thickness; (* .5-7) state cross sectional area (* .*.1-5) or 'special beam sections' (* .*.6)

FIGURE 1: Analysis of provision and placing of in situ concrete, adapted from

CESMM 3

Critiquing the conventional approach to costing, Hoare and Broome (2001) argue that bills of quantities (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, p20). 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 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.

5. Design

Since civil engineering and architectural designs describe finished products which are physical objects, a substance ontology would appear to provide them with an adequate basis in reality. It is, of course, recognised that these product descriptions are subject to the process of implementation. However, the planning and control of this process also resonates a substance ontology which is reflected in contractual arrangements. Thus, the design and the implementation of the design are treated as separate products. This creates a conflict-prone interface between the processes of design and design realization.

This 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). The conventionally-understood and tacitly accepted reasons for any such variation 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 products. Thus, 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 variability of construction processes are recognised to an extent in BS 5606, which provides a formula for site personnel to calculate their 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).

6. Programming

Hoare and Broome's (2001) critique of Bills of Quantities is associated with an initiative to overhaul contractual arrangements and replace them with what might at first sight appear to be a flow based analysis of production. Thus, the Engineering and Construction Contract offers an alternative to the Bill of Quantities in an Activity Schedule, which measures work, rather than materials. This method of analysis puts the programme of work at the centre of the contract. However, rather than a true process analysis, what this method entails is precisely the kind of task breakdown that Koskela (2000) criticises.

To illustrate this point, a case study is taken from a small project to widen a short stretch of highway. Work was also taking place on a railway bridge midway down the site. It was intended to overlap the contracts for four weeks. This would allow the contractor to begin work at one end of the site and leave the middle of the site free by the time it was required. However, a three week delay in finishing the railway bridge meant that the contractor had to break off work and recommence at the far end of the site. This had a knock on effect for the statutory undertakers, who were programmed to follow the contractor up the site. Furthermore, the delay was magnified to six weeks, since the statutory undertakers could not commence until the contractor had almost finished the middle section.

This much was agreed between the contractor and consultant. However, when the statutory undertakers finally began work, further knock on delays were experienced, which became the subject of a claim for seventeen weeks delay. The consultant resisted accepting the client's responsibility for this additional delay. The basis of the disagreement was as follows. The information supplied by the employer as a basis for tender, specified that each of four statutory undertakers would require eight weeks to perform their work. The exact form in which this was done is reproduced in figure 2. The contract on this project was the ICE fifth edition, under Clause Fourteen of which, the contractor is required to supply a programme for the work, within twenty-one days of the tender being accepted. In this programme, the contractor had allotted eight weeks during which all four of the statutory undertakers were expected to

perform their work simultaneously and specified how this would be co-ordinated. The Resident Engineer (RE) responded that the Clause Fourteen programme was unrealistic and the matter was left unresolved. When the contractor asked to be compensated for the resulting delays, arguing that the whole delay was a result of the original overrun, the RE refused, arguing that the amount of work the statutory undertakers had to do had been underestimated on the original programme. He explained his reasoning in a research interview, as follows:

“Now, it says here that the following time periods are required by the statutory undertakers. [company A] will require six weeks notice to start and their works will take eight weeks. An’ it’s the same for each damn one, six weeks notice to start and each and every one will take eight weeks to do their work. Now, I can’t understand why [the contractors] seem to think, they interpret that to mean there’s an eight week period during which they’re all going to do their work. I just cannot see that in that er document, all it’s telling them, its telling me, that each and every one of them, they’ve got eight weeks of work to do out there, now obviously if they all started on the same day, they might all finish together after eight weeks. On the other hand, you might say well, [company A] start first, and then a week later somebody else starts and then a week later somebody else starts, an you get a bit of a stagger between the two so they’re not all on top of each other. An’ I responded to their Clause Fourteen Programme in this vein, saying I think for you to have them all starting on the same day and all finishing on the same day is just impracticable. An’ I said I thought a more realistic stance would have been having a week's start say, between each one.”

The contractor argued that they had programmed the work in accordance with the information and provided a programme for the statutory undertakers on this basis. This dispute originates in a failure (on the part of either the contractor or client's team, or both) to take full account of the temporal properties of the flow of work. Thus, the requirements for the statutory works are presented as quantities of time into which the specified tasks can be slotted. These time slots are then arranged by the contractor on a Gantt chart and subjected to a critical path analysis. This analysis provides a temporal ordering of tasks, such that tasks which cannot be begun until others are finished are programmed to follow in logical order. However, this analysis does not provide for the contingent interaction between tasks. Thus, the analysis, provided

neither for the reasonable possibility of a delay in completing the work on the bridge, nor for the difficulties of co-ordinating four teams of workers to work alongside each other. This, despite the common sense observation of the Resident Engineer that the programme was "just impracticable".

“The following time periods are required by the Statutory Undertakers

Statutory Undertakers	Notice for Start-on-Site	Cable/Pipe Laying & joints
[Company A]	6 weeks	8 weeks
[Company B]	6 weeks	8 weeks
[Company C]	6 weeks	8 weeks
[Company D]	6 weeks	8 weeks

The above times for cable laying and jointing are based on one gang working and its given a free access to the whole of their works.

FIGURE 2: Extract from tender documents

7. Discussion and Conclusion

If recent innovations in production management such as the Toyota Production System and Lean Production do indeed represent an ontological shift from a metaphysics of substance to a metaphysics of flow, then there would appear to be a considerable body of work in science education that promises to act as a guide to future developments in construction education (*viz* Chi 1992; Chi & Roscoe 2002; Chi, Slotta, & de Leeuw 1994; Itza-Ortiz, Rebello & Zollman 2003).

The evidence presented here seems to point in that direction. 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 (hypothesis one); they are also open to subversion by more temporally based analyses (hypothesis two). If Rooke, Seymour & Fellows (2003, 2004) characterisation of a claims culture is to be accepted, then it is possible to surmise that this consists, at least in part, of an unofficial sub-culture of process thinking that has emerged in a parasitic relationship to an 'official' culture of substance based thinking.

Such an analysis finds some support in the concrete cover studies also. Here it can be seen that the treatment of design as a product, rather than a process in iterative communication with that of construction, leads to a second set of problems. 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). The presence of a transformation view of production, with the implication of an underlying substance ontology is clearly detectable here. Again, the data tends to confirm hypotheses one and two.

In contrast, the Last PlannerTM system replaces *ad hoc*, compensatory responses with an integrated system for planning and controlling the entire process. In this process based method, construction is treated as the completion of design. Thus, design, an abstract set of intentions whose implications can only be discovered through implementation, is modified in the course of execution, as the inevitable uncertainties of local conditions are negotiated. Data generated in planning and control of site work are fed-back via a weekly work plan, through look-ahead to master schedule in a complete learning loop, such that design and schedule can be progressively refined. The process based nature of the Last Planner System tends to confirm hypothesis three.

The Engineering and Construction Contract represents another attempt to reform the construction industry which would appear to owe something to a process ontology. The contract was designed using flow charts to map contractual procedures, allowing for

However, the contract is dependent on project planning methods which seem to owe more to a substance metaphysics. Thus, a central role is given to the contractor's programme of work, a method of task decomposition that, as seen in the highways example above, grants insufficient attention to the interface between sub-tasks and leads to unplanned delays. The contradiction that arises in this contract between process and substance thinking lends support to hypotheses three and four.

Thus, support has been found for all four of the hypotheses. However, none of them

can be taken as proven. The following caveats should be born in mind. First, the selection of cases, while intended to be representative of key features of the construction process, was nonetheless made with the intention of seeking confirmatory evidence. A stronger test would be to seek dis-confirming instances (Popper 1992). Second, while two contrasting ways of thinking have been identified and these have been located in the philosophical literature, management theory and ethnographic accounts of practice, the consequences of characterising these as ontologies has not been fully explored. It has been noted above that in the course of analysis, the strong requirement of unique adequacy has been relaxed, raising the possibility that rival interpretations of the data may be viable. Finally, these methodological concerns, as well as attendant practical ones, can only be ultimately satisfied by the design and successful implementation of educational techniques that address and overcome the pedagogic obstacles to process based construction management. This must be the next step forward.

8. References

Ballard, G. (2000) *The Last Planner System of Production Control*, A thesis submitted to the Faculty of Engineering of The University of Birmingham for the degree of Doctor of Philosophy, School of Civil Engineering, Faculty of Engineering, The University of Birmingham.

Ballard, G. & Howell, G. (1998) 'Shielding Production: Essential Step in Production Control,' *Journal of Construction Engineering and Management*, **124**(1):11-17.

British Standards Institution (1989) *The Theory of Tolerances*, BS 5606, London

Chi, M. T. H. (1992) 'Conceptual change within and across ontological categories: examples from learning and discovery in science', in R. Giere (ed.) *Cognitive Models of Science: Minnesota studies in the philosophy of science*, University of Minnesota Press, Minneapolis, 129-86.

Chi, M. T. H. (in press) 'Cognitive Understanding Levels,' in *Encyclopedia of Psychology*, APA & Oxford University Press.

Chi, M. T. H. & Roscoe, R. D. (2002) 'The Processes and Challenges of Conceptual Change,' in M. Limón & L. Mason (eds.) *Reconsidering Conceptual Change: Issues in Theory and Practice*, Kluwer Academic Publishers 3-27.

Chi, M. T. H., Slotta, J. D. & de Leeuw, N. (1994) 'From Things to Processes: A Theory of Conceptual Change for Learning Science Concepts,' in *Learning and Instruction*, **4**:27-43.

Chia, R. (2002). The Production of Management Knowledge: Philosophical Underpinnings of Research Design. In: Partington, D. (ed.), *Essential Skills for Management Research*. SAGE Publications, London. Pp. 1 – 19.

Fraczek, J. (1979) ACI Survey of Concrete Structure Errors, *Concrete International*, December, 14-20.

- Garfinkel, H. (2002) *Ethnomethodology's Program: Working out Durkheim's Aphorism*, Rowman & Littlefield, Lanham.
- Garfinkel, H. & Wieder, D. L. (1992) 'Two Incommensurable, Asymmetrically Alternate Technologies of Social Analysis', in G. Watson & R. M. Seiler (eds.), *Text in Context*, Sage, London, pp. 175-206.
- Hammersley, M. & Atkinson, P. (1994) *Ethnography; Principles in Practice* (Second Edition) Routledge, London.
- Hoare, D. J. & Broome, J. C. (2001) 'Bills of Quantities Versus Activity Schedules for Civil Engineering Projects,' in *Journal of Construction Procurement*, 7(1):11-26.
- Institute of Civil Engineers (1991) *CESMM 3: Civil Engineering Standard Method of Measurement*, (third edition) Thomas Telford, London.
- Institute of Civil Engineers (1998) *The engineering and construction contract: an NEC document*, (second edition) Thomas Telford, London.
- Institute of Civil Engineers (2005) *The Civil Engineering Standard Method of Measurement (CESMM)*, accessed on 19th April 2006, http://www.ice.org.uk/knowledge/contracts_cesmm.asp
- Itza-Ortiz, S. F., Rebello, S. & Zollman, D. (2003) 'Students' models of Newton's second law in mechanics and electromagnetism', in *European Journal of Physics* 25:81-89. <http://web.phys.ksu.edu/papers/2004/ejp-salomon.pdf>
- Jennings, A. R. (1995) *Accounting and Finance for Building and Surveying*, Macmillan, Basingstoke.
- Juran, J. M. & Gryna, F. M. (1993) *Quality Planning and Analysis*, (third edition) McGraw Hill, New York.
- Koskela, L. (1992) 'Application of the New Production Philosophy to Construction',

Technical Report No 72, Centre for Integrated Facility Engineering, Stanford University, California.

Koskela, L. (2000). *An exploration towards a production theory and its application to construction*, VTT Technical Research Centre of Finland, VTT Publication 408.

Koskela, L. (2004) 'Making-Do – The Eighth Category of Waste,' *Proceedings of the 12th Annual Conference of the International Group for Lean Construction*, August 3-5, LO-School, Elsinore, pp. 3 – 12.

Koskela, L. & Kagioglou, M. (2005) 'On the metaphysics of production' *Proceedings of the 13th Annual Conference of the International Group for Lean Construction*, 19th-21st July, Sydney.

http://www.iglc.net/conferences/2005/papers/session01/05_059_Koskela_Kagioglou.pdf

Popper, K. R. (1992) *The Logic of Scientific Discovery*, (with added appendices and footnotes) Routledge, London.

Rescher, N. (2000) *Process Philosophy*, University of Pittsburgh Press, Pittsburgh.

Roochnik, D. (2004) *Retrieving the Ancients*. Blackwell Publishing.

Shingo, S. (1988) *Non-stock production :the Shingo system for continuous improvement*, Productivity Press, Cambridge Mass.

Rooke, J. (2001) *Researching Culture on Construction Projects*, A thesis submitted to the University of Birmingham for the degree of Doctor of Philosophy, School of Engineering, Birmingham.

Rooke, J. & Clark, L. (2005) 'Learning, knowledge and authority on site: a case study of safety practice', *Building Research and Information*, **33**(6):561-570.

Rooke, J. & Seymour, D. (2005) 'Studies of Work: Achieving Hybrid Disciplines in

IT Design and Management Studies', *Human Studies* **28**(2):205-221.

Rooke, J., Seymour, D. & Fellows, R. (2003) 'The Claims Culture; A Taxonomy of Industry Attitudes', in *Construction Management and Economics*, **21**:167-174.

Rooke, J., Seymour, D. & Fellows, R. (2004) 'Planning for Claims; An Ethnography of Industry Culture', in *Construction Management and Economics*, **22**:655-662.

Schwartzman, H. B. (1993) *Ethnography in Organizations*, Sage, Newbury Park.

Seymour, D., Shamma-Toma, M. & Clark, L. (1997) 'Limitations of the use of tolerances for communicating design requirements to site,' *Engineering, Construction & Architectural Management*, **4**(1):3-23.

Shamma-Toma, M., Seymour, D. & Clark, L. (1996) 'The effectiveness of formal quality management systems in achieving the required cover in reinforced concrete,' *Construction Management & Economics*, **14**(4):353-364.

Shamma-Toma, M., Seymour, D. & Clark, L. (1998) 'Obstacles to implementing total quality management in the UK construction industry,' *Construction Management & Economics*, **16**(2):177-192.