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Models and Metaphors: Some Applications of Complexity Theory for Design, Construction and Property Management

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ABSTRACT

Complexity thinking may have both modelling and metaphorical applications in the design, construction and servicing of the built environment. In production theory, queuing and variation have been central in generating improvement initiatives. The complexity of these phenomena in construction suggests that non-linear and complex mathematical techniques such as fuzzy logic, cellular automata and attractors, may be applicable to their analysis. Some issues are: the definition of phenomena in a mathematically usable way; the functionality of available software; the possibility of going beyond representational modelling. Much work in management studies, rather than employing mathematical techniques, draws metaphorically on insights into complexity. Metaphor may enlighten or confuse. Is metaphorical application of complexity ideas simply a first step towards the application of mathematical techniques, or does the mathematical insight contribute to the development of a non-mathematical mode of thought? The metaphor of a 'commentary machine' is suggested as a possible way forward.

Keywords: Metaphor, Modelling, Management, Production Theory, Software.

1. INTRODUCTION

This paper seeks to explore how complexity theory can help resolve problems of organization in the Built Environment Industry. Complexity concepts can be operationalised as either modelling or metaphor. We outline some parameters for the complex system under consideration and examine the application of complexity theory to the study of business. In conclusion, we focus on a particular metaphor which indicates the possibility of specifying the details of complex settings.

2. PRODUCTION AND SERVICE IN THE BUILT ENVIRONMENT

It is undeniable that companies working to design, build and maintain the built environment are operating in situations of complexity, both with regard to their environments and their internal operations. Considerations that feature in companies' decision making processes will include *inter alia*:

- Fluctuations in demand;
- Evolving procurement and contracting strategies;
- Pressures to reduce costs, while improving timeliness and quality;
- Pressure to maintain profitability;
- A range of competing initiatives to improve company performance;
- Differing and sometimes conflicting professional and occupational standards and loyalties;
- The salience of industry-wide standards;
- The need to improve safety performance and environmental sustainability;
- The need to balance technological and organizational innovation against familiar and reliable methods.

3. METAPHOR

Morgan asserts the importance of metaphor in understanding organizations. His claim that “our theories and explanations of organizational life are based on metaphors” (p. 12) may be an over-generalisation. However, he is undeniably correct in identifying the metaphorical process, in which we “understand one element of experience in terms of another” (p. 13), as one which is important to theory making.

Several benefits of the metaphorical use of complexity thinking can be identified, for instance the importance of connectivity and interdependence in complex systems can be used to stress the collective nature of organisation. Mittleton-Kelly (2003) reiterates a common social science observation that the an individual’s contribution to a team is constrained by what the team will permit (Parsons 1968; Hofstede 2002).

She also notes that the social ecosystem in which an organisation exists consists of other organisations which both affect that organisation and are affected by it. She uses the concept of exaptation to emphasise the importance of allowing an organisation's members to explore the 'space of possibilities' that exists, thus encouraging lateral thinking (de Bono 1971). Along with Gershenson & Heylighen (2005) she stresses the concepts of self-organisation, feedback and attractors to describing organisational change.

Thus, complexity thinking is taken primarily as a stimulus to more flexible management styles, reinforcing what has long been a trend in management studies (Peters & Waterman 1982; Handy 1994).

4. MODELLING

The use of mathematical modelling techniques for simulating complex systems within the built environment is controversial (Richardson et al. 2000). Often, a prediction of the future is expected as an output from a mathematical equation. Guastello (1995) states that “prediction of future states is possible in the near term, but could decay rapidly as we try to extend further into the future.” Though we know that maths cannot predict the future, we are disappointed when it does not.

Non-linear and complex mathematical modelling techniques have been applied to supply chain and workforce management (Guastello 1995) and cellular automata for the modelling of regions (Allen 1997). Techniques which may be useful include fuzzy logic, cellular automata, chaos theory, catastrophe theory and fractals for example, basic explanations of which can be found in many texts (Berry 1996; Codd 1968; Guastello 1995; Kosko 1993; Steeb 2005; von Neumann 1966; Wolfram 2002). Complex techniques are rarely used in isolation (Steeb 2005), but more often in combination with other modelling techniques. For example, non-linear dynamic systems may be linked to game theory to investigate long range planning and reactive management in the construction trades (Guastello 1995). Fuzzy logic helps to explain the shades of grey in between the black and white of many established techniques.

Some suggest that whilst complex systems need not follow traditional modelling techniques, complex phenomena do not always need complex theory to explain them; complexity can emerge from simple beginnings (Wolfram 2002).

There is much literature on agent based models, multi-agent systems and Complex Adaptive Systems theory (the latter term originating from the work of John Holland and others at the Santa Fe) (Carroll & Burton 2000; Dijkstra et al. 2001; McCarthy et al. 2006; Payr & Trappl 2004; Robertson 2005; Seese & Schlottmann 2003; Shen et al. 2001). These can demonstrate complex non-linear interactions that allow the emergence of new unpredictable properties in the system, allowing flexibility and a network based interaction representation of Built Environment Systems. Many focus on ‘software agents’, ignoring the special characteristics of human agents, but may still be useful to model teams, processes and organisations, for example. Agent based models such as Conway's Game of Life have been in widespread use for around a decade.

Agent based software programs available on the internet include StarLogo (http://education.mit.edu/starlogo/) and JADE (http://jade.tilab.com). StarLogo is a basic programmable modelling environment for exploring the workings of decentralized systems (there is also an extension StarLogo TNG). It is designed as an introduction for students and researchers and has a colourful and usable interface. JADE (Java Agent DEvelopment Framework) is a software framework to develop agent-based applications, but seems to assume that agent = software agent, limiting its application to organizational systems.

MATLAB ® (www.mathsworks.com) is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numeric computation. The many add-ons (toolboxes) it contains allows for flexibility in analysis and simulation. At its basic level, MATLAB allows for the development of agents and their environment, whilst the toolboxes provide a wider range of application and accuracy.

Where a modelling application is intended, it is necessary to identify countable phenomena that can be transformed into factors in the model. A starting point for this enterprise is to be found in the work of the *International Group for Lean Construction,* particularly that done on flows (Koskela's 2000; Bertelsen, Koskela, Henrich & Rooke 2006). One important class of phenomena is that of queues. Queueing theory has been applied to factory production (Hopp & Spearman 2001). Lean construction thinkers are working towards identifying critical flows which might also be amenable to mathematical analysis. Given the chronically indeterminate nature of construction processes, it seems likely that these will have the characteristics of complex systems.

However, modelling applications may also be seen as metaphorical. If we accept that, whatever their basis, models represent simplifications of a system, then models are not so different from metaphors, which at their core are meant to be symbolic representations of something else. Indeed models (and diagrams) are aids to solving problems, not solutions in themselves. Thus, another way of viewing the work of Mittleton-Kelly (2003), or Gershenson & Heylighen (2005) is as outlining the concepts necessary to the creation of such models. The most promising fields for this endeavour appear to be economics and geography (Arthur 1990; 1995; Allen 1997).

5. SIMPLE COMPLEXITY AND COMPLICATING SIMPLICITY

However, in some cases, The appearance of complexity may be generated by the inadequacy of our (non-mathematical) analytic methods. This can be one consequence of treating human organizational phenomena as amenable to exhaustive causal analysis. The use of mental terms (for example, disposition terms such as mood, attitude, personality, culture) in a non-causal analysis can provide simpler formulations. Moreover, metaphors can be misleading and it is worth looking more closely at how they are used in practice: in what ways they help; how they break down and with what consequences. For instance Gershenson & Heylighen (2005) use the metaphor of complexity to attempt an escape from the restrictive bonds of Cartesian thought:

> “From the cybernetic perspective, there is no strict boundary between the 'material' and the 'mental' components: the information stored in my notebook is as much a part of my memory as is the information stored in my brain, and my email connection is as much part of my communication equipment as the nerves that control my speech.” (Gershenson & Heylighen 2005:56)

However, the new conceptual space created is relatively minor, compared with that achieved by phenomenological and linguistic philosophers (Schutz 1962; Wittgenstein 1958; Ryle 1963). Thus, they find it necessary to resort to the Cartesian dualism of a universal objective reality and local subjective perception, in order to explain differences in perception. This, in turn, allows them to cling to the familiarity of a clockwork Newtonian universe, comforting though concealed, but it leaves the residual problem of how objective (physical) reality is to be reconciled with subjective (mental) perception (Button, Coulter, Lee & Sharrock 1995). There is a vast literature on this problem, which has proved an intractable theoretical inconvenience. It is most easily removed by recognising that: [a] objectivity is itself a local achievement by situated perceptive beings; and that [b] the relaxation of distinctions is a linguistic move, rather than an ontological discovery.

The concept of dissipative structures may also be misleading. Although, history is an important consideration in human systems, it would seem that complexity thinking has little to offer to an already highly developed field. In directing attention to the relatively impoverished concept of history employed in chemistry, Mittleton-Kelly runs the risk of overlooking the rich analysis that already exists in the sociological (Weber 1976, Parsons 1951) and management traditions (e.g. Kanter 1985).

Wolfram’s (2002) discovery that computer programmes operating simple rules can generate highly complex patterns provides for an ambiguity in the description of such programmes. Viewed as sets of rules, the programmes may be described as simple; viewed as generators of outcomes, they may be described as complex. [Note also that the rules look simple because of the way they are stated, using boxes (Wolfram 2002:27) they would no doubt look more complicated if stated exclusively in English.] It is apparent that the perception of complexity depends upon how a given mathematical phenomenon is viewed. Using the metaphor of the disturbances produced by two speedboats whose paths continuously interweave on an otherwise placid sea, Burke (1969) explicated such a phenomenon with regard to human behaviour; the complex, or chaotic outcomes can be seen as the interaction of only two elements. That complexity can be simple is confirmed by Gershenson & Heylighen (2005), who state that complexity can consist of as little as two parts. Sacks (1972) made a similar observation, speculating that it may not be that human behaviour is complicated that makes it so baffling to social scientists, but the fact that human behaviour is self-characterising.

Sacks (1963) had previously employed the elaborate metaphor of a 'commentary machine' to illustrate the problem of social research. This machine functions to produce a commentary on its own activities. These are observable and in principle describable by social scientists, but these descriptions have the same ontological status as the descriptions produced by the machine itself. Indeed, they are often descriptions of descriptions. This presents problems related to both: how naturally produced descriptions are to be scientifically treated; and the nature of the claims that can be make for social scientists' own descriptions. The working out of these conundrums has been one source of the principle of unique adequacy (UA) discussed below. Note that the two parts here are the scientist (observer) and the subject (observed), the complexity is in the relationship between them. It would be mistaken to believe that the two parts are, for instance, the action and its self characterisation, as Ryle's (1963) critique of Cartesianism clearly shows.

Snowden's Cynefin framework (Snowden 2002; Kurtz & Snowden 2003) is, among other things, an attempt to avoid such inappropriate categorisations of the world. Rather than categorising the world directly, it offers a categorisation of ways of looking at the world, with the additional proviso that the category boundaries are permeable and flexible. Thus, Cynefin provides a tool for achieving negotiatated order (Strauss, Schatzman, Bucher, Ehrlich, Sabshin 1964). Such tools provide a means of both understanding and creating systems in which:

> “the possibility that interactions between large numbers of entities, each entity responding to others on the basis of its own local organizing principles, will produce coherent patterns with the potential for novelty in certain conditions” (Stacey 2001, p. 93

It may be that reaching such an understanding depends upon conducting research to meet the UA requirement of methods (Garfinkel 2002; Garfinkel & Wieder 1992). Livingston (1987) illustrates the significance of this requirement with reference to the patterns of movement formed by crowds crossing the road at a busy intersection. Overhead video tape footage reveals that crowds typically make wedge shaped formations. There would seem to be three alternative strategies for answering the question how these formations are generated: [1] using the video tape material, to take an overview of the whole system, analysing the flows as they occur to determine possible chains of causality; [2] analyse the behaviour of single entities, in order to discover their local organising principles. This second course is clearly appropriate to complex systems. However, for human systems, a third possibility exists. [3] We may interview participants in crowds, or participate in crowds ourselves, in order to obtain an inside view of how the patterns are generated. In this way, the *decisions* of the crowd's members provide an additional rich source of whose complexity the UA requirement is designed to address. The requirement has two forms, both of which:

> “are founded on the principle that the activities and procedures of persons in a setting can best be accounted for in terms of the understandings that those persons have of that setting. Thus, the task of the ethnographer is to render a clear description of those understandings, rather than offer an explanatory theory.” (Rooke, Seymour & Fellows 2004:656)

In its weak form, the UA requirement demands that “the analyst must be *vulgarly* competent in the local production and reflexively natural accountability of the phenomenon” (Garfinkel and Wieder 1992:182). Thus, to analyse a decision making process adequately, we must know what any participant in the process would ordinarily know about that process. This knowledge, expressed as competence, is the kind referred to by Ryle (1963) as 'knowing how'. In this form the requirement is proposed as a criterion for adequate ethnography, the most certain method for acquiring such knowledge being participant observation. However, it is possible to usefully apply it to other forms of enquiry, such as interviews and questionnaires. Thus, for instance, a questionnaire designed by someone who had no direct knowledge of the process under study is likely to contain irrelevant, misleading or even meaningless questions.

The strong requirement concerns the reporting of research. It demands that the methods of analysis used to describe a process should be derived directly from that process. This assumes that the methods that participants use in the process of making a decision are sufficient to the purpose of producing an account of that decision. It is proposed as a standard for the description of any phenomenon which is composed of (and by) conscious beings who are able to produce an account of their own activities. It is proposed that methods of analysis which are alien to the analysed setting (thus introducing a theoretical spin to the description) must involve some distortion. This requirement is proposed as a criterion for ethnomethodology. However, reports have been written outside this discipline which, at least in part, meet this form of the requirement (e.g. Dutton & Starbuck 1971). It currently informs much of the work being done in the field of Computer Supported Co-operative Work (CSCW). For instance, Button & Sharrock (2002) have offered a UA description of the routine decision making processes of a production scheduler in a print works.

Intrinsic complexity could be said to lie in several areas of the activity, for instance: the craft like nature of the printing process; variability in the capability and performance of printing machines; conflicts between the technology used by the design house customers and the ability of the printing equipment to replicate this. Intrinsic complexity could also be seen to be inherent in the relationships between the customer and the printers, since these are taken as a given, although actual instantiations of uncertainties and 'buggeration' factors may vary from case to case.

Induced complexity would seem to emanate from: the nature and variability of the work-breakdown structures within the printing organisation; the relationships between the various roles of (e.g.) account holder, scheduler, shop floor personnel, management; the range and depth of both the formal and tacit knowledge and experience of the individual scheduler; the variation and evolution of organisational units from job to job and shift to shift.

Decision making in this context is affected by both the above and by certain elements of what could be called 'emergent behaviour' or 'system interoperability'. The former, because any combination of type of job, different team, different shift, different machines, degree of foreseeable problems etc. will result in a potential event (e.g. job stopped, job delayed, etc.) which will require decisions made on the schedule to be regularly revisited in a partially structured *ad hoc* manner. The latter, because the overall printing capability is not an integrated or interoperable system and perhaps, given its nature, could never be. In a sense the scheduler functions to integrate the system, often acting on the fly. It is not clear how much of the decision making process is repeated in terms of process, variables taken into account, and people consulted. By this we mean: does a set of decision making processes and variables come into play for similar sets of problems, or it is a totally random process which varies from scheduler to scheduler.

Though no similar studies exist as yet of the design, construction or maintenance of the built environment, there are many parallels that may be drawn. For instance, the role of the scheduler as an absorber of inter-task complexity is highly relevant to the sometimes seemingly intractable problems of co-ordination on construction projects. Some key decision making techniques are:

- eliminating the need to consider alternatives (though possibly holding these in reserve) by producing a single workable schedule;
- simplifying the interactions between tasks to a smaller set of known ones (while possibly retaining others mentally);
- leaving intra-task complexities, that will have effect once the task commences, and may, via the inter-task interactions, affect other tasks, to the task operators to fix, based on their knowledge and experience.

6. CONCLUSION

We have identified two forms of complexity thinking: metaphor and modelling. The immediately apparent use of metaphor in the examples we have considered is rhetorical, as suits the use of a poetic device. Complexity metaphors can be used to call attention to important features of organization and to advocate particular styles of management.

The modelling form is sometimes mistakenly thought to enable prediction. It should rather be thought of as a means of exploring possibilities, particularly those that would otherwise not be apparent.

Mathematical models are in themselves metaphorical in form, relating mathematical techniques to actual existing systems. Metaphors may provide a common ground for explanation of the maths. This is, in fact, common practice in mathematical education. However, we must realise that a solution to a maths problem is simply that. We must be sure we are clear about the questions we are asking if we are to find the answers that we seek.

Furthermore, it is important to accept and understand that different people have different mental models and as such will view metaphors in different ways. We have noted some ways in which applications of complexity theory to organizational analysis may be misleading. It is important in avoiding these pitfalls that we consider the ways in which complexity is being used. The notion of history, for instance, may be important in identifying a quality of systems that it may then be possible for mathematicians to model. It is hardly likely in itself to add anything to social science understanding.

Finally, we have considered a metaphor arising not from complexity theory, but from social science. The metaphor of the commentary machine leads us away from rhetoric, towards specification of the actual psycho-social processes that constitute the stuff out of which real life organizations are built. We have shown how reports of such specifications can reveal actual features of complex organizational settings.

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