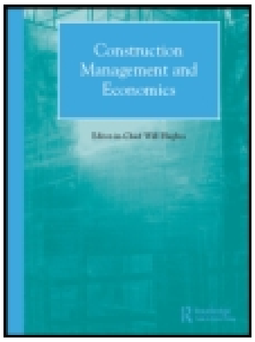

Construction Management and Economics

ISSN: 0144-6193 (Print) 1466-433X (Online) Journal homepage: https://www.tandfonline.com/loi/rcme20

Implementing innovation in construction: contexts, relative boundedness and actor-network theory

Chris Harty

To cite this article: Chris Harty (2008) Implementing innovation in construction: contexts, relative boundedness and actor-network theory, Construction Management and Economics, 26:10, 1029-1041, DOI: 10.1080/01446190802298413

To link to this article: https://doi.org/10.1080/01446190802298413

Construction Management and Economics (October 2008) **26**, 1029–1041

Implementing innovation in construction: contexts, relative boundedness and actor-network theory

CHRIS HARTY*

School of Construction Management and Engineering, University of Reading, Whiteknights, Reading, RG6 6AW, UK

Received 9 February 2007; accepted 23 June 2008

Theoretical understanding of the implementation and use of innovations within construction contexts is discussed and developed. It is argued that both the rhetoric of the 'improvement agenda' within construction and theories of innovation fail to account for the complex contexts and disparate perspectives which characterize construction work. To address this, the concept of relative boundedness is offered. Relatively unbounded innovation is characterized by a lack of a coherent central driving force or mediator with the ability to reconcile potential conflicts and overcome resistance to implementation. This is a situation not exclusive to, but certainly indicative of, much construction project work. Drawing on empirical material from the implementation of new design and coordination technologies on a large construction project, the concept is developed, concentrating on the negotiations and translations implementation mobilized. An actor-network theory (ANT) approach is adopted, which emphasizes the roles that both human actors and non-human agents play in the performance and outcomes of these interactions. Three aspects of how relative boundedness is constituted and affected are described; through the robustness of existing practices and expectations, through the delegation of interests on to technological artefacts and through the mobilization of actors and artefacts to constrain and limit the scope of negotiations over new technology implementation.

Keywords: Innovation, implementation, information technology, context, relative boundedness, actor-network theory.

Introduction

The aim of this paper is to introduce and develop the concept of the relative boundedness of innovation. Current thinking about innovation in construction often fails to account for the multiple and contrasting perspectives found within construction contexts. Also, it can be assumed that innovation is driven by coherent and unilateral agreement over its expected outcomes, and is mediated through the largely unexplored efforts of specific individuals. Relative boundedness is positioned as addressing this gap. It is a dynamic concept, which considers the ways that processes of innovation can bring in or exclude a wide range of actors and material artefacts as they play out. In order to develop the concept, empirical material from the implementation of new design technologies on a large construction project is discussed. An actor-network theory approach (ANT) is used to trace and unpack the interactions occurring around implementation of these artefacts. In doing so, different aspects of how relative boundedness is constituted are revealed. Through considering relative boundedness, the implementation of innovation in construction can be better grounded in the realities of its contexts and can help to strengthen the connection between theoretical debates and actual practice.

The 'state' of construction and construction research

Construction is often considered to lag behind other sectors both in terms of its inherent abilities to innovate and develop better ways of working, and in its seeming inability to adopt innovations from other areas. Much academic research sets out this position of construction's backwardness (e.g. Winch, 1998; Gann, 2000;

*E-mail: c.f.harty@reading.ac.uk

Construction Management and Economics
ISSN 0144-6193 print/ISSN 1466-433X online
http://www.tandf.co.uk/journals
DOI: 10.1080/01446190802298413

Nicolini *et al.*, 2001; Woudhaysen and Abley, 2004) and there is also a long history of high profile reports contributing to this view of the need for widespread improvement of the sector's practices (e.g. Emmerson, 1962; Higgin and Jessop, 1965; Latham, 1994). Other areas such as automotive industry have regularly been held up as shining examples of efficient reorganization and utilization of innovative technologies and processes, from which construction might extract methods for its own improvement (e.g. Egan, 1998; CRISP, 1999).

However, the suitability and applicability to construction of innovations originating elsewhere has been questioned (e.g. Sexton and Barret, 2003; Winch, 2003) and the need to understand the characteristics of construction contexts has been elucidated (Bresnen and Marshall, 2001). Also, fundamental contextual differences between construction and other areas have been revealed (Green *et al.*, 2005). It has further been suggested that a rift between current theorizing about construction work and real construction activity hinders both the understanding and the actual processes of innovating (Koskela and Vrijhoef, 2001). Despite this, the positioning of construction as the poor cousin of other sectors in need of wholesale reconfiguration retains a great deal of currency. The argument offered here is that this 'improvement agenda' fails to account for or connect to the specificities of innovating within construction contexts. There is also a tendency to reproduce the assumption that implementation can be kept within a coherent sphere of influence, usually the single firm, or fail to offer alternative frameworks if this is not the case.

This assumption is also reproduced in the 'implications for practitioners' that are sometimes tagged on to academic papers. These often amount to little more than brief mantras with little or no appreciation of how to practically manage innovation processes and the different actors who are affected by them. The need to break down barriers to innovation and the need to resolve conflicts between actors are generally revealed as (certainly not invalid) conclusions rather than as starting positions to unpack how to address them (e.g. Rooke and Clark, 2005; Price and Chahal, 2006). Where conflict is more substantively addressed, it is often positioned as part of a wider struggle between management and labour in the control of workers' activities inspired by Harry Braverman's (1974) seminal but arguably dated work on deskilling (e.g. Clarke and Wall, 2000; Goodrum and Gangwar, 2004). In organizational literature more widely, although not yet within construction, research inspired by the work of Michel Foucault (1991) positions resistance as a reaction to increasing surveillance of workers' activities, especially those which are IT based (e.g. Knights and McCabe, 2003). However the plethora of contrasting interpretations of Foucault's work, especially regarding arguments over its determinism and the role of subjectivity make it difficult to sustain strong claims about how such resistance occurs and can be mitigated.

Alongside assumptions about the ability to bring about adoption of innovations there is a dearth of research that investigates in qualitative detail processes of implementing innovations within construction. Construction often presents a terrain with no single or coherent driving force behind implementation in which innovation must be grounded. Construction activity involves numerous firms, actors and disciplines working together (or occasionally exploiting each other) to produce largely bespoke solutions for clients. Innovation that is oriented towards changing the ways that construction firms operate must therefore be implemented across this inter-organizational landscape.

Positioning innovation in construction

Given these complexities, it is interesting that the dominant model of innovation in construction positions the sector as largely reactive. There are two aspects to this positioning. The first is that construction innovation is seen as a response to external needs, especially those of clients. For instance, Gann (2000) shows that in the late 19th and early 20th centuries 'electric power replaced steam and water power in factories, leading to major changes in the design and construction of buildings' (Gann, 2000, p. 51).

We can also look to contemporary buildings, such as the Swiss Re Tower in London, to see the output of cutting edge construction. Also, more modest but equally important buildings, with improved environmental performance, increased lifespan or flexible configurations result from similar innovative efforts.

The second aspect is that construction implements innovations originating from elsewhere, rather than developing its own solutions. This often takes the form of adopting new products and again Gann (2000) catalogues an impressive range of innovations, most notable in the R&D activities of suppliers and manufacturers of materials and components, which are eventually incorporated into the sector's practices.

While it is certainly the case that innovation occurs in response to external needs, and through importing products and techniques from outside, this does not encapsulate all of the innovative activity that occurs in the sector. For instance problem solving can lead to innovative solutions, and is largely based on the experiential knowledge of those involved (Li and Love, 1998). But often these ideas are mobilized as monolithic accounts in support of improvement agendas which portray the sector as laggard and uninnovative. This moves debates away from important issues such as precisely how emerging needs or imported innovations are addressed and embedded in construction activities. Rather the industry is presented as tropistically bending towards external stimulus, with little internal dynamism to innovation and change.

Construction as a low tech, low innovating sector

This view of the sector as less than proactive is reaffirmed by its characterization as low tech, and as demonstrating low levels of innovation. But care needs to be taken with such positioning and measurements. Sectoral comparisons based around technology characteristics such as that developed by Pavitt (1984; also Tidd *et al.*, 1997) place construction as a supplier-led sector, where again the main emphasis for innovation strategy is 'to use technology from elsewhere to reinforce other competitive advantages' (Tidd *et al.*, 1997, p. 108).

However, it is recognized that such categorization necessarily entails simplification and that sectors are not homogeneous but compromised of different types of firms and that specific actors can demonstrate more than one particular characteristic. Construction, with its diverse range of firms and competencies, would seem to be no exception. Green *et al.* (2005) when comparing construction with the aerospace sector, argue that the proliferation of small firms in construction makes the comparison of one with the other uneven, and makes the implementation of innovative practices much more problematic in the former than the latter. A similar perspective is offered by Winch, who argues that 'the standard industrial classifications (SIC) used as the basis for national accounts do not allow the comparison of like with like' (Winch, 2003, p. 652).

In addition, much innovative activity within the wider remit of construction, such as that associated with product design and carried out by design firms, is excluded from any analyses. Also, von Tunzelmann and Acha (2005) argue that the notion of any 'low tech' sector is difficult to sustain empirically, and that 'high' technologies permeate different sectors, characterized as high, medium or low tech, to varied extents. Other work similarly argues that high tech sectors are highly dependent on relationships with sectors considered low tech, not least in terms of selling high tech products to them (Robertson and Patel, 2007). The substantial utilization of IT of various forms within construction projects, and the global strength of companies such as AutoCAD who supply a large proportion of design software to the sector, resonate strongly with these views.

Construction innovation in context

In assessing the salience of such categorizations of 'construction' and its innovative activities, it is clear that the sector's inherent diversity makes such homogenization problematic. In view of this, coupled with the difficulties of differentiating between activities extending across sectors, such as the development and implementation of ICT systems, a more detailed, grounded approach to understanding activities of innovating can be advocated.

Slaughter's seminal paper (1998) represents a typology of innovation in construction, using established concepts from the wider innovation literature. In this schema, innovation can be dichotomized as incremental or radical; incremental innovation consists of small changes that build on existing ideas and expertise, and that occur frequently; radical innovation is much rarer, and signifies a break with existing knowledge and activity. Another axis of comparison extends between modular and architectural innovation. The former represents change at the level of a component, but which continues to interface with other components in the same way as before. The latter does not affect the component level, but represents major changes in the ways these components interface and connect. The final type, system innovation, represents the integration of a number of otherwise discrete innovations into a coordinated system.

These different models are aligned on a scale according to the extent of change they represent, from small change (incremental) to major change (radical). Also implied is the extent to which innovation can be contained within, or extend across, organizational (or component) boundaries. However, the arrangement of these models lacks any consideration of the different perspectives from which innovating can be viewed, or of the different implications of the same innovation being implemented in different contexts. Incremental innovation in one context might generate significant and radical consequences in another. Innovation could be categorized as component at the level of an overall process but in fact be systemic at more localized levels. Radical technological innovation could occur at component level and have little effect on wider processes. This changing of categorization has been described as the 'hypercube of innovation' (Afuah and Bahram, 1995) to denote the multiple 'faces' innovation can present from different perspectives. These sorts of consequences can only be deduced by considering the specific contexts in which innovation occurs, something that is generally absent from more theoretical discussion.

Mediating innovation

Accounting for these different perspectives and multiple contexts requires a focus on the actual activities that constitute innovating. For mediating the process of coordinating system innovation, Slaughter places great emphasis on the ability of individuals; 'the innovator also is able to … achieve coordination and cooperation actors the system(s)' (Slaughter, 1998, p. 228). But there is no unpacking of precisely what such an innovator might do to achieve successful innovation, or what happens when this key innovator is absent. Rather a coherent and unitary centre to the innovation process is assumed.

Winch (1998) agrees that studies of innovation in construction have failed to take sufficient notice of its particular contexts and characteristics. He proposes a model of innovating based on an innovation superstructure and innovation infrastructure, joined together through the efforts of system integrators. Such individuals manage the transition of innovation from single instances to wider adoption within the superstructure of the sector as a whole.

Winch's approach is grounded in the complexities of the inter-organizational project basis of construction work. Research on complex products and systems (CoPS—see Miller *et al.*, 1995; Hobday, 2000; Hobday *et al.*, 2000), upon which Winch's work builds, presents an argument for understanding complex project-based work involving one-off bespoke products (such as buildings or IT networks) differently from other forms based around repeated routines and large volumes of products. Rather than progressing through a product-led lifecycle model from multiple solutions or products to maturity and a stable, dominant design, as is the case for much manufacturing activity, CoPS remain in a fluid phase, with continually evolving architectures, customized components and emerging client requirements. Incremental cycles of innovating are not the business of CoPS, and the challenge they face is in managing this complexity and integrating and coordinating these disparate elements. As such, and like Winch's model, a strong system integrator is needed: 'CoPS have to account for the elements of architectural, system and complement knowledge which must remain within the boundaries of the systems integrator firm' (Hobday *et al.*, 2000, p. 796).

Similar to Slaughter's innovators, successful mediation of innovation in CoPS also relies on a centralized integrator with the capability to oversee and manage the whole system.

Relative boundedness

Where there is a strong systems integrator centralized mediation can effectively steer and manage implementation processes. Such efforts can be seen as relatively bounded; there is a coherent centre that aligns the various parties and entities involved. But what happens if innovation's effects or repercussions extend beyond the control or sphere of influence of the implementer—if it is relatively unbounded? In such cases, how does implementation play out?

The notion of relative boundedness is offered to address this gap, not solely derived from the characteristics of the innovation itself, but also accounting for the contexts into which it is implemented. This means that implementation of the same innovation may be less or more bounded in one location than in another and hence generates different challenges and different outcomes. Considering relative boundedness avoids common assumptions that innovation always takes place within coherent and unilateral landscapes. It also brings more clearly into focus the range of pre-existing conditions and practices into which an innovation is implemented.

This consideration of contexts also resonates with a growing awareness of the ongoing nature of innovation beyond activities of implementation, and the role that use and users play in developing and shaping technologies. Edgerton (2006) argues that the technological dynamics of the 20th century were not driven by innovation, but rather how innovations were picked up or rejected by users, and combined with existing artefacts. Studies in the sociology of technology have similarly described the innovative activities of users, as artefacts are appropriated into everyday practices (e.g. Oudshoorn and Pinch, 2003). In this work, both the artefact, or process, and its uses are co-produced through implementation and can transform innovations in ways unforeseen by developers and implementers (Bijker, 1992). These ideas are important in highlighting how the characteristics of an innovation are transformed and shaped in practice, rather than simply diffused as stable, unchanging artefacts with fixed characteristics. Whyte's (2003) conclusions to a study of virtual reality use within construction similarly argue that different users in different contexts have diverse sets of requirements, and hence need tailored, rather than standardized, technological solutions. Harty (forthcoming) also shows how the same technological artefact is implemented and constituted very differently in different organizational contexts.

Within construction, the appreciation of boundedness is highly significant in terms of attempts to reconfigure sequences and practices of inter-organizational project work. Construction work shows seemingly indelible and intractable patterns such as the partial exchange of information leading to reworking (see Love *et al.*, 1999), recourse to litigation, and inflexible sequences in which different actors are mobilized on a project. In such contexts the effects of implementation cannot always be tightly controlled and constrained, and extend beyond the influence of a single organization or individual. In order to successfully innovate in such a relatively unbounded context, the cooperation or alignment of multiple actors and spheres of influence from across different organizations would be required. Considering the relative boundedness of an innovation's implementation recognizes this, and can contribute to bridging the gaps between calls for reconfiguring construction work and detailed exploration of how innovation plays out in specific contexts.

Approaching the study of relatively unbounded innovation

The consideration of relative boundedness in practice requires an approach that can follow and trace the dynamics of implementation, wherever they might lead. In order to develop the concept of relative boundedness here, an actor-network theory (ANT) approach is taken. ANT is centrally concerned with the way various people, ideas and things come together within networks and are held in place or become disassociated and reconstituted. Although little used in construction management research, ANT has found considerable purchase in wider organizational (e.g. Lee and Hassard, 1999; Steen *et al.*, 2006) and information systems research (e.g. Hanseth *et al.*, 2004).

Its ability to enrich the notion of relative boundedness rests on two important features. First is the notion of the actor-network itself. This is not a static concept, but rather emphasizes the continual transformations and reconfigurations of actors, artefacts and practices that occur through interaction. The co-production of innovations and ways of using them are framed as sets of associations being formed, held together or pulled apart and reconfigured, a process of 'heterogeneous engineering' (Law, 1986, 1992). Methodologically, the extent of the actor-network is not defined *a priori*; it is not restricted by organizational, project or sectoral boundaries, or limited to the interests of specific actors. Rather, it traces associations wherever they lead. This makes it an apposite approach for tracing the effects and repercussions of innovation as it occurs.

Secondly, ANT rejects distinctions between human and non-human, instead adhering to an ontological symmetry where both technological artefacts and human actors are able to constitute other elements and themselves be constituted through the very process of interaction. This allows the consideration of the active roles of material and technological actants, as well as human actors, as these heterogeneous entities interact. ANT is therefore well suited to study processes of change and disruption which involve the interaction of many actors and non-human entities (Latour, 2005).

The empirical material discussed is taken from a larger study of the development, implementation and use of new ICTs on a substantial construction project (Harty, 2005). The process of the research started with one particular technology—a building services modelling tool—and traced its interactions across as well as beyond the project. These associations led to other technologies, various users and developers and other associated actors, such as project managers and IT support. The methods employed on the study consisted of participant observation both within the project's offices and at those of ICT developers, over a period of 12 months. This was followed by a series of interviews, which were intended both to capture through discussion the activities observed, and to further explore the wider expectations and visions of different actors, including developers as well as users, informing implementation.

The material utilized here is organized as follows. Initially, a discussion of the vision of a technologically mediated construction process the project's management espoused, and which informed their innovative efforts, is given. Following this, three examples from the implementation process are offered, each of which demonstrates a different aspect of how relative boundedness was constituted, and its effects. First, the transformation of visions and the incorporation of influences external to the project are considered. Secondly, the processes of delegating agency from technology developers outside the project to non-human actors within it are discussed. Thirdly, the role of intermediaries in providing a focus for negotiation and achieving consensus between heterogeneous actors is described.

Constituting visions of electronically coordinated construction

The concept of relative boundedness is able to incorporate the existing ideas, practices and visions which form the context into which an innovation is placed. Innovation rarely occurs with a *tabula rasa*; rather innovations must reconfigure existing ways of thinking and working to accommodate them, as well as potentially be reconfigured themselves. The technologies implemented and the practices and processes developed on the project discussed here were part of a widespread vision advocating their potential to significantly reconfigure existing ways of project working. The vision stresses that by unlocking the potential of communication and collaboration technologies alongside three-dimensional (3D) CAD and other design and information management tools, the process of construction can be seamlessly and electronically coordinated. By integrating the software used across construction design, separate elements can be assembled in a virtual environment to produce an electronic version of the building, complete with every detail of the eventual real thing. This would ensure that the designs are spatially coordinated—that everything fits together correctly—a process known as 'clash detection'. Any coordination problems can be rectified before onsite construction begins. In addition, coordinating the design digitally would remove much of the costs of paper and printing from the project, allow clear accountability trails to be constructed with respect to design decisions, and enable the virtual model of the building to be utilized for facility management. This vision, which was espoused by the client and across the senior management of the project, was presented as heralding the technological driving force through which to bring about a radical and more efficient way of working.

It is important to note that this vision is neither an abstract, disconnected idea, nor is it confined to a particular project, but is constituted from a multiplicity of actors, objects and associations; construction clients seeking for ways to improve cost-effectiveness, software vendors who want to sell new products, construction organizations seeking to improve profits. The technological artefacts enrolled into the vision are manifold; as well as hardware such as desktop PCs and central servers there are operating systems, communications software, document management and a plethora of CAD and engineering packages. The networks in and through which such visions are configured and circulated are complex and heterogeneous.

The wider notions of the general improvement agenda described earlier are also important in providing a backdrop of the need for change. Academic research on such technologies contributes to reifying the connection between their potential and general improvement of the industry's practices. Bhavnani *et al.* (1996) argue that existing CAD systems are used in sub-optimal ways, and Marir and Aouad (1998), Rowlinson and Yates (2003), and Schreyer *et al.* (2005) also outline the potential of various CAD and middleware technologies to facilitate better coordination between the disparate actors involved in construction design.

Within this literature, there is acknowledgement of the organizational as well as the technological challenges of implementing such technologies (e.g. Bouchlaghem *et al.*, 2005) and the requirement for wide-ranging change across the construction process to reap the full benefits of artefacts such as 3D CAD models as coordination devices (Hartmann and Fischer, 2005). However, their subject matter is less concerned with the implications that such changes might bring for current configurations and practices of construction, or how their implementation might play out. This leaves a gap between technological possibility and how to realize this potential in practice. This is especially the case when these ideas are mobilized in support of the construction improvement agenda, where assumptions are often held that new technologies in themselves are sufficient to drive changes in organization and practice.

This notion that technology drives progress was readily apparent on the project discussed here, with a smooth continuum drawn from paper-based design practice, through the use of 2D CAD and sharing of electronic design information, to modelling in three dimensions and using technology as the centre of collaboration:

> I just think we're going through a change—my opinion is that we'll all be on it [3D CAD] … it's just another step, that's all. (Interview with CAD manager)

However, the actual implementation of these technologies was much more contested than this notion of a seamless progression would suggest.

Issue 1: Translating visions and actor-networks

The transformations required to bring about the vision of a reconfigured and electronically coordinated construction process draw in many different actors; the project discussed here involved some 400 staff from different construction firms and disciplines during its design phases. These actors have to be cajoled, convinced and enrolled into adopting and supporting the artefacts in a way consistent with the vision if it is to come to fruition; they and their ways of working must be translated into configurations that support electronic coordination. But actors bring their own ideas, expectations and existing practices with them, derived from the interactions they are and have been instantiated in through, for example, professional training and previous work experiences. Accounting for these extends the network of associations beyond the boundaries of the project, and beyond immediate and local contexts.

As implementation began, and the vision was communicated to project staff, immediate problems became apparent over the reliance on both 3D modelling techniques and an electronically centred process. Team managers, engineers and designers, and CAD drafters were sceptical of any attempts to remove 2D drafting, and other non-computerized tools from their practices:

> … to be honest, any form of planning in any construction system is always primarily 2D—everybody thinks in 2D to start with. (Interview with CAD drafter)

These existing practices were very robust in the face of attempts to translate them. This was not just about convention and familiarity, but was integral to the ways that designers and drafters worked. Observing staff at work, a variety of methods could be seen, including use of paper and pen sketches and 2D CAD, with designs going through several iterations as they became gradually more fixed and certain. Desks were littered with paper printouts and hand-written notes and sketches. Printouts retained some sort of advantage for error-checking over computer screens:

> You can get it finished on these big screens, but then you send it to print, and you can see the mistakes as it comes out of the printer—but you won't see them on the screen … it's not the same as an A0 or A1 piece of paper. (Interview with CAD drafter)

The centrality of paper to the design process is an issue that has been highlighted before (e.g. Carter, 1993; Henderson, 1995, 1999). Materials such as paper were not peripheral to computer-based work, but active parts of the practices of design and drafting, constituted through interactions between heterogeneous agents. Printers and printouts to check errors and rulers to check dimensions on those printouts were just some of the non-human actors that constituted practices of design and CAD drafting. It was a significant challenge to develop new processes that dispensed with these artefacts:

> All that [experimenting with different designs] happens by hand, by bits of modelling stuff … then all of that goes out to CAD guys to draw up … you couldn't say that you have to build this job on IT and that's it—you get people bringing in pads, hiding them under the desk. (Interview with architect)

This is not to say that it is an impossible aim to remove paper from the process of drafting. Rather, the associations through which the project staff's existing practices of designing and drafting were constituted were highly resistant to such a reconfiguration, and the translation of practices to exclude them was strongly resisted across the project:

> You always get resistance—people are resistant to change. People like to work the way they work … If people are just being pig ignorant I just leave them to it … there are some teams out there that don't want to use it. (Interview with IT support manager)

This resistance was not necessarily a function of individuals being 'pig-ignorant'; rather the vision and artefacts being implemented did not account for the other material objects that were an integral part of the practices of designing and drafting. These processes were not just rejected out of hand, but were seen as discontinuous with existing ways of working. In other words, for many of the project's staff they were highly radical, rather than incremental changes to existing practice.

Very early on the original desire to replace paper and 2D printouts (which formed a large part of the economic argument for working in this new way) was overturned. The vision underestimated the importance of certain material actors in the process of designing and drafting; actors that were almost impossible to exclude from project practices. It also underestimated the influence of associations from outside the project in which project staff were grounded. Attempts to implement new practices on the project could not be isolated from these wider associations and so the process became relatively more unbounded and escaped the confines of the project space. The engagement with these wider associations led to the emergence of a transformed vision that incorporated paper-based practices.

It is important to note here that the specific technologies to be implemented on the project play no part in these transformations; hence their specific characteristics have no bearing on this transformation of the project vision and cannot help to explain what occurred. The key issue central to understanding what was happening is the way negotiations around moving from 2D-based to 3D-based design practices within the project unavoidably became relatively unbounded as the implementation played out.

Issue 2: Delegating agency and enrolling actors

It is not only those objects associated with existing practices that can present problems during implementation; the very technological artefacts at the centre of the process can also prove to be somewhat obdurate. For the building services teams on the project, there were a number of 3D modelling options to evaluate. Designing building services requires the coordination of complex systems such as heating and plumbing, and several software products were available to undertake this in three dimensions. Negotiations were held over which software to adopt, revolving around specifying the functions designers and drafters required, while maintaining an inter-compatible format between different software for electronic file and data exchange. But the negotiations stopped at the point where it was found that some products would fulfil some, but none all, of the requirements for the project, revealing a rather partial landscape of technological possibility. The vision of coordinated working was out of step with the actual technologies available.

To try and rectify this, a list of suggestions for specific changes was produced to take to various software developers. Interoperability was key, as this would allow a number of products, each with its own advantages and omissions, to be used alongside each other. However these requests were met with little enthusiasm, with one developer even producing a 41-page document outlining the reasons why the changes could not be accommodated.

One of the key aspects of an ANT approach is the granting of the ability to act to non-human agents, a process described as the delegation or displacement of agency from human actors to non-human actants (Akrich 1992; Akrich and Latour 1992). Actants possess or contain scripts of use, be they simple devices, such as the door closer discussed by Latour (1992), or more complex ones like computers and software. These scripts represent the possible ways of using the artefacts, which then have the ability to constrain some ways of using and enable others. In line with this, Woolgar (1991) describes a process of 'configuring the user'. Developers endow the technological artefacts they produce with certain assumptions and constraints based on their visions of intended users and these scripts of use allow certain ways of using and prohibit others. Importantly, these scripts represent not only the attempts of developers to satisfy user requirements, but also the developers' own expectations and associations.

The developers of the software under negotiation for use on the project designed into them scripts of possible users, and possible uses, precluding others. The intended users of these products were CAD drafters largely using paper printouts as the method of exchanging design information between disciplines and between different firms, the norm in most construction work. Issues of interoperability and compatibility with other building services software was not part of their intended use, hence the problems of interoperability revealed by the implementation process on the project. To many of the project's managers, these artefacts were largely convergent with their vision, requiring only slight adaptation to allow interoperability. However, these artefacts could not be associated in the ways desired by the project's managers and the project vision without recourse to the software's developers. But for these developers, non-interoperability was a fundamental part of their delegations of intended use on to these artefacts.

As was the case with using paper and 2D drafting, it is not that it would be impossible to introduce inter-compatibility with other products into the artefacts, but outside the project these products inhabit a competitive environment, with different developers vying for sales within a fairly new and undecided market. In this context, inter-compatibility and the ability to export to rival formats could reduce the requirement for customers to invest in a particular package. Hence interoperability was resisted through the software actants produced by these developers as representing their own interests, as well as those of potential users.

These negotiations, then, show how actants such as the 3D CAD software constrained development of both the artefacts and the practices around them in line with the idea of electronic coordination. Indeed, these technologies could not be brought into the project without bringing with them the displaced or delegated intentions of their developers, in terms of imagined users and desired ways of using. This once more demonstrates implementation becoming relatively unbounded, but this time through processes of delegation. It was again not possible to keep implementation confined within the project itself, and appeals to developers to reconfigure their products and allow interoperability were largely unsuccessful, due to their broader positioning against alternative technologies.

Issue 3: Mediating interests and converging practices

The preceding examples show how pre-existing associations of existing practices and technologies, and of developers and products from outside were unavoidably drawn into interactions within the project. Attempts to enrol and align these with the project vision failed due to their robustness and the wider consequences of their translation, which were at odds with the project vision. But in other disciplines within the project, more stable associations of technologies and practices around 3D modelling and electronic coordination were evident. For structural steel there was one clear product to use for both design and fabrication. However, there was still considerable debate over precisely how to use this software in a consistent way. The debate centred on layering standards—the way that complex drawings and models are split into separate, overlaid sections. Layering is necessary to stop single drawings becoming too complicated and messy and to allow specific aspects of a drawing to be edited and revised without affecting other parts. But there is no single standard format of layering conventions, with various different 'standards' often developed for different projects. Consistent layering conventions are crucial to producing multiple and complex designs that can be understood, shared and combined across different users and disciplines.

In order to produce such a layering method, a draft document was drawn up outlining standard practices to be used on the project. This became the locus for negotiations over these practices, and acted as an intermediary between the project's management, IT support, structural engineers, CAD drafters and others. Such intermediaries can be positioned as devices that circulate or travel within and between networks, acting as models representing a particular location in the interests of another; in this case representing the activities of CAD users in the interest of the project's management and their vision. Such 'centres of calculation' mobilize these devices to enact control over others; by allowing the former to know and predict the actions of the latter (Latour, 1987).

Intermediaries have been positioned as unchanging, as immutable mobiles which ensure that the particular representations produced by the centre are not changed or corrupted by other agents. But in this case the document was subject to numerous redrafts as it circulated between different groups of actors, effectively multiple centres. Rather than act to enforce a particular way of working on project engineers and drafters, it acted as a mediator between centres as it was gradually translated to incorporate various entities' interests. After several iterations or circulations, it came to represent practices that satisfied the engineers and drafters, the project's management and vision and current technological possibilities. The co-production of this document emerged through the interaction of many different actors and interests within the project.

In addition, the importance of pre-existing associations of ideas, practices and artefacts around producing structural steel designs in 3D from outside the project should not be underestimated. But whereas the previous example showed how such wider associations can introduce barriers and challenges to attempts at enrolment and alignment, here they served to orient the negotiations towards consensus and convergence. For example the director of a large design practice who had a number of staff working on the project, but no direct involvement, saw benefits in coordinating structural steel design and fabrication using shared 3D modelling:

> We're pushing it [the structural steel design] to be 3D—it's the easiest bloody way to draw it—it's in our interests to push it … All we are saying is, all we're boiling down to is that people should coordinate better—it's the biggest problem in the industry—people need to coordinate round something—is 3D the best way of doing that? I don't know … but in streamlining the process [we are] taking out the historical barriers—its nonsensical that we create things electronically, send them out on paper to the contractor who's got a little man in the corner typing them into a bending machine. (Interview with Design Practice Director)

The intentions and visions of this particular actor were not necessarily in favour of integrated 3D CAD coordination in the same way as the official vision; in fact there was strong opposition to full 3D modelling and coordination across the whole project. However, crucially, support for implementing this new way of working within structural steel design intersected with the further-reaching project vision. The unity of support for these particular ways of working from the project's management and influential actors outside the project contributed to the emergence of a coherent set of practices. In comparison to the case of the building services software, greater synergy between project and influential external actors was evident, as was a more stable set of pre-existing associations between 3D structural steel modelling technologies and practices. However, the emergence of agreed project standards still required an alliance between contrasting actors within and outside the project.

This also suggests another aspect to relative boundedness. Although events did once again escape the boundaries of the project, the mediating role of the standards document provided a nexus for debate, and effectively pushed wider arguments over the project vision of full coordination to the margins. Its mobility enabled it to travel between different sets of actors; its mutability enabled it to be successively shaped as it travelled. But its specificity—its central concern with standards rather than wider issues of electronic coordination and the project vision—maintained a relatively bounded space for discussion. It acted as a screen from broader debates over wholesale transformation towards 3D and electronic coordination. It effectively created a boundary around the layering debates, which although extended beyond the project, excluded some of the more contentious aspects of the vision that the building services negotiations could not avoid.

Relative boundedness in practice

In the cases above, considering relative boundedness is essential in explaining what was happening in practice. It proved impossible to isolate the project from wider influences. As more and more actors (whether human or non-human) were engaged with, they brought with them different constraints and possibilities. As Latour (2005) argues, 'in each course of action a great variety of agents seem to barge in and displace the original goals' (Latour, 2005, p. 22). The empirical cases certainly concur with this, and also reveal different mechanisms that affected the relative boundedness of the implementation process. These cases describe how the process of implementation could not be contained or bound within the confines of a specific project or set of actors. Rather it continually escaped these boundaries, bringing in influences from outside. Moreover, these influences often stood in stark contrast to the project's aims, resulting in resistance to implementation or reconfiguration of the vision informing it.

Moreover, three distinct aspects of how relative boundedness is constituted and affected are distinguished. In the first case, the innovation process intersected with robust and pre-existing associations that extended outside the domain of the project. Practices such as the use of paper and other non-IT artefacts for designing and checking proved impossible to exclude from the project, and to break apart and transform into exclusively digital activities. Whereas the project vision placed such actants as nothing more than a residual hang-over from pre-CAD practices, they were in fact central to activities of CAD designing and drafting. Although considered an incremental shift, the implications of moving to 3D coordination and rejecting non-IT artefacts were radical and profound in terms of the existing practices of project staff. In the second example, processes of delegation served to extend the innovation process beyond the boundaries of the project, into the domains of technology developers. The scripts of use within various technologies introduced different and unexpected constraints inside the project. These were grounded in developers' own notions of intended uses and users of their products. Challenging these through requests for interoperability served only to further reveal the disparities between the project vision and the wider contexts in which developers are located, rather than resolve them. The final case showed that a particular object—the standards document—was able to mediate between actors both within and without the project. But although this once again shows the innovation process escaping the confines of the project, the document also enforced boundedness. It acted as a containing device, effectively shielding the interactions around shaping structural steel design practices from wider contests over the vision of full coordination. In this sense it served to increase the relative boundedness of the process.

Conclusions

The concept of the relative boundedness of innovation has been developed in order to understand the dynamics and often unexpected consequences of attempts to innovate within construction work. The concept is a response to the ways that innovation in construction is positioned. On the one hand, industry and government rhetoric calls for increased innovation, positioning the sector as the poor cousin of other, more innovative areas. On the other, there is an absence of substantive discussions of how innovation is and might be brought about within the particular contexts of construction. Current models of construction innovation can lack detail, and do not reflect the messy, complex and dynamic realities of construction activity, with the burden of implementation attributed to specific individuals who can orchestrate and control implementation processes. The contribution of the concept of relative boundedness is in addressing these shortcomings. It is derived from the specificities of innovation in particular contexts. By considering the dynamics of the contexts of implementation, a much more nuanced and detailed understanding of the implementation process can be developed. This is not only useful in conceptualizing the implementation of innovations, but also has significant implications for practitioners in incorporating and accounting for, rather than excluding, contextual realities from policy rhetoric, industry guidance and actual practice.

In the empirical cases discussed, existing approaches to innovation are not able to fully engage with the complex dynamics and the often unexpected twists and turns of these efforts to innovate. Neither the technologies, nor the actors involved could muster a unilateral or coherent driving force behind implementation, and a complex series of negotiations resulted in unexpected outcomes. The concept of relative boundedness is crucial in making sense of these, in accounting for the various influences, both human and non-human, which shaped the implementation process. These are not stories of the diffusion of a finalized and stable black box, even if some actors assumed this was the case. Neither are they studies of the enforcement of one set of technologies or practices by managers on (potentially resisting) users. They instead describe the interplay between different actors, artefacts and interests, none of which has final arbitration over the shape of the practices, or technologies, which emerge from them.

At a finer level, three specific aspects of relative boundedness are revealed. The first relates to how pre-existing expectations, assumptions and practices from outside are difficult to exclude from or contain within a specific context or innovative initiative. The second aspect similarly relates to the difficulties of excluding innovation in context from wider domains, but realized through a process of delegating intentions on to material artefacts. The very artefacts at the centre of the innovation process bring with them the intentions, concerns and perspectives of their developers. The third aspect relates to the maintenance of boundedness by specific actors or artefacts. Strategies for limiting the scope for negotiations, in the case above in concentrating negotiations around specific details, can maintain a more bounded and less contested space, reducing the complexity of, and potential influences on, the innovation process.

So how can the concept of relative boundedness inform research? A key issue here is that by tracing networks of association, the researcher follows the connections between different actors and actants, irrespective of project or firm boundaries. The remit of the research is derived from how far the networks extend. Who, or what, is being drawn into negotiations around the innovation process? Who and what is being excluded from them? And how are these inclusions and exclusions being undertaken? These are key questions in assessing how bounded or distributed the innovation process is. It must also be stressed that networks are dynamic, tracing themselves how these associations are broken down and reconfigured, or remain stable, as innovation is enacted.

The different aspects of relative boundedness offered also orient the researcher towards specific empirical details. Existing practices and the expectations and assumptions that they incorporate might be more or less robust, and can have a significant effect on whether and how new ways of working emerge through innovation processes. The politicized character of technology development and the ways in which developers indelibly affect the artefacts they produce are also important in considering how contained or unbounded specific innovative activity might be. Mechanisms and activities that attempt to constrain the networks and actors involved in innovating can also be looked for, as efforts to manage and maintain boundedness.

The role of material agents should also be stressed as an important aspect of relative boundedness and in the cases above such entities played a range of important roles. In the first case, pens and paper were integral aspects of design practices distributed across human and non-human actors. In the second, the software artefacts represented instantiations of their developers' external interests. In the third, the standards document acted as an intermediary that enforced boundaries around layering conventions, excluding wider and more controversial debates over technological change. Again, without consideration of these roles, both methodologically and conceptually, what was occurring in practice is difficult to explain.

Relative boundedness is a concept that challenges the assumptions of coherent implementation processes. It is oriented towards unpacking the negotiations and alignments that constitute attempts to innovate rather than positioning mediators as able to smooth over competing concerns in practice. It is through following such dynamic interactions, and accounting for a range of influences, actors and artefacts that innovation can be better understood. This can not only enrich our understanding of construction innovation, but also can contribute to innovation studies more widely. Although comparisons between sectors should be handled with care, construction is not unique in its project organization, or in the presence of contrasting visions and aims within the domains of implementation. Building up detailed descriptions of the activities that constitute implementation and accounting for processes that reduce and increase relative boundedness can contribute to wider debates on the nature of innovation in other complex landscapes.

References

Afuah, A.N. and Bahram, N. (1995) The hypercube of innovation. *Research Policy*, **24**, 51–76.

Akrich, M. (1992) The de-scription of technical objects, in Bijker, W. and Law, J. (eds) *Shaping Technology/Building Society: Studies in Sociotechnical Change*, MIT Press, Cambridge, MA, pp. 205–24.

Akrich, M. and Latour, B. (1992) A summary of a convenient vocabulary for the semiotics of human and nonhuman assemblies, in Bijker, W. and Law, J. (eds) *Shaping Technology/Building Society: Studies in Sociotechnical Change*, MIT Press, Cambridge, MA, pp. 259–64.

Bhavnani, S.K., Flemming, U., Forsythe, D.E., Garrett, J.H., Shaw, D.S. and Tsai, A. (1996) CAD usage in an architectural office: from observations to active assistance. *Automation in Construction*, **5**, 243–55.

Bijker, W. (1992) The social construction of fluorescent lighting, or how an artifact was invented in its diffusion stage, in Bijker, W. and Law, J. (eds) *Shaping Technology/Building Society: Studies in Sociotechnical Change*, MIT Press, Cambridge, MA, pp. 75–102.

Bouchlaghem, D., Shang, D., Whyte, J.K. and Ganah, A. (2005) Visualisation in architecture, engineering and construction. *Automation in Construction*, **14**, 287–95.

Braverman, H. (1974) *Labor and Monopoly Capital: The Degradation of Work in the Twentieth Century*, Monthly Review Press, New York.

Bresnen, M. and Marshall, N. (2001) Understanding the diffusion and application of new management ideas in construction. *Engineering, Construction and Architectural Management*, **8**(5/6), 335–45.

Carter, K. (1993) *Computer Aided Design: Back to the Drawing Board*. Technical Report EPC-1993-107, Rank Xerox, Cambridge.

Clarke, L. and Wall, C. (2000) Craft versus industry: the division of labour in European housing construction. *Construction Management and Economics*, **18**, 689–98.

CRISP (1999) Linking construction research and innovation to research and innovation in other sectors, in *CRISP Workshop Proceedings*, Davis Langdon Consultancy, 24 June, London.

Edgerton, D. (2006) *The Shock of the Old Technology and Global History since 1900*, Profile Books, London.

Egan, J. (1998) *Rethinking Construction*, Construction Task Force Report for Department of the Environment, Transport and the Regions, HMSO, London.

Emmerson, H. (1962) *Survey of the Problems before the Construction Industry*, HMSO, London.

Foucault, M. (1991) *Discipline and Punish: The Birth of the Prison*, Penguin, London.

Gann, D. (2000) *Building Innovation: Complex Constructs in a Changing World*, Thomas Telford, London.

Goodrum, P.M. and Gangwar, M. (2004) The relationship between changes in equipment technology and wages in the construction industry. *Construction Management and Economics*, **22**, 291–301.

Green, S., Fernie, S. and Weller, S. (2005) Making sense of supply chain management: a comparative study of aerospace and construction. *Construction Management and Economics*, **23**, 579–93.

Hanseth, O., Ananestad, M. and Berg, M. (2004) Actor network theory and information systems. What's so special? *Information Technology and People*, **17**(2), 116–23.

Hartmann, T. and Fischer, M. (2007) Supporting the constructability review with 3D/4D models. *Building Research & Information*, **35**(1), 70–80.

Harty, C. (forthcoming) Implementing innovation: designers, user and actor-networks. *Technology Analysis and Strategic Management*.

Harty, C. (2005) Innovation in construction: a sociology of technology approach. *Building Research and Information*, **33**(6), 512–22.

Henderson, K. (1995) The visual culture of engineers, in Star, S.L. (ed.) *The Cultures of Computing*, Blackwell, Oxford, pp. 196–218.

Henderson, K. (1999) *On Line and on Paper Visual Representations, Visual Culture and Computer Graphics in Design Engineering*, MIT Press, Cambridge, MA.

Higgin, G. and Jessop, N. (1965) *Communication in the Building Industry*, Tavistock Publications, London.

Hobday, M. (2000) The project-based organisation: an ideal form for managing complex products and systems? *Research Policy*, **29**, 871–93.

Hobday, M., Rush, H. and Tidd, J. (2000) Innovation in complex products and systems. *Research Policy*, **29**, 793–804.

Knights, D. and McCabe, D. (2003) Governing through teamwork: reconstituting subjectivity in a call centre. *Journal of Management Studies*, **40**(7), 1587–619.

Koskela, L. and Vrijhoef, R. (2001) Is the current theory of construction a hindrance to innovation? *Building Research & Information*, **29**(3), 197–207.

Latham, M. (1994) *Constructing the Team*, Final Report of the Government/Industry Review of Procurement and Contractual Arrangements in the UK Construction Industry, HMSO, London.

Latour, B. (1987) *Science in Action: How to Follow Engineers and Scientists through Society*, Open University Press, Milton Keynes.

Latour, B. (1992) Where are the missing masses? The sociology of a few mundane objects, in Bijker, W. and Law, J. (eds) *Shaping Technology/Building Society: Studies in Sociotechnical Change*, MIT Press, Cambridge, MA, pp. 225–58.

Latour, B. (2005) *Reassembling the Social: An Introduction to Actor-Network-Theory*, Oxford University Press, Oxford.

Law, J. (1986) On methods of long distance control: vessels, navigation and the Portuguese route to India, in Law, J. (ed.) *Power, Action and Belief: A New Sociology of Knowledge*, Routledge Kegan Paul, London, pp. 234–63.

Law, J. (1992) Notes on the theory of the actor-network: ordering, strategy and heterogeneity. *Systems Practice*, **5**, 379–93.

Lee, N. and Hassard, J. (1999) Organisation unbound: actor-network theory, research strategy and institutional flexibility. *Organization*, **6**(3), 391–404.

Li, H. and Love, P. (1998) Developing a theory of construction problem solving. *Construction Management and Economics*, **16**, 721–7.

Love, P., Li, H. and Mandal, P. (1999) Rework: a symptom of a dysfunctional supply chain. *European Journal of Purchasing and Supply Management*, **5**(1), 1–11.

Marir, F. and Aouad, G. (1998) OSCONCAD: a model-based CAD system integrated with computer applications. *ITcon*, **3**, 25–43.

Miller, R., Leroux-Demers, T. and Olleros, X. (1995) Innovation in complex system industries: the case of flight simulation. *Industrial and Corporate Change*, **4**(2), 363–400.

Nicolini, N., Holti, R. and Smalley, M. (2001) Integrating project activities: the theory and practice of managing the supply chain through clusters. *Construction Management and Economics*, **19**, 37–47.

Oudshoorn, N. and Pinch, T. (2003) *How Users Matter: The Co-Construction of Users and Technologies*, MIT Press, Cambridge, MA.

Pavitt, K. (1984) Sectoral patterns of technical change: towards a taxonomy and a theory. *Research Policy*, **13**, 343–73.

Price, A.D.F. and Chahal, K. (2006) A strategic framework for change management. *Construction Management and Economics*, **24**, 237–51.

Robertson, P.L. and Patel, P.R. (2007) New wine in old bottles: technological diffusion in developed countries. *Research Policy*, **36**, 708–21.

Rooke, J. and Clark, L. (2005) Learning, knowledge and authority on site: a case study of safety practice. *Building Research & Information*, **33**(6), 561–70.

Rowlinson, S. and Yates, D. (2003) nDCAD: a virtual change agent for professions and procurement systems? *Construction Management and Economics*, **21**, 849–57.

Schreyer, M., Hartmann, T. and Fischer, M. (2005) Supporting project meetings with concurrent inter-operability in a construction information workspace. *ITcon*, **10**, 153–67.

Sexton, M. and Barrett, P. (2003) A literature synthesis of innovation in small construction firms: insights, ambiguities and question. *Construction Management and Economics*, **21**, 613–22.

Slaughter, E.S. (1998) Models of construction innovation. *Journal of Construction Engineering and Management*, **124**(3), 226–31.

Steen, J., Coopmans, C. and Whyte, J.K. (2006) Structure and agency? Actor-network theory and strategic organization. *Strategic Organization*, **4**(3), 303–12.

Tidd, J., Bessant, J. and Pavitt, K. (1997) *Managing Innovation Integrating Technological, Market and Organizational Change*, John Wiley and Sons, Chichester.

Von Tunzelmann, N. and Acha, V. (2005) Innovation in 'low tech' industries, in Fagerberg, J., Mowery, D.C. and Nelson, R.R. (eds) *The Oxford Handbook of Innovation*, Oxford University Press, Oxford, pp. 407–32.

Whyte, J.K. (2003) Innovation and users: virtual reality in the construction sector. *Construction Management and Economics*, **21**, 565–72.

Winch, G. (1998) Zephyrs of creative destruction: understanding the management of innovation in construction. *Building Research & Information*, **26**(4), 268–79.

Winch, G. (2003) How innovative is construction? Comparing aggregated data on construction innovation and other sectors—a case of apples and pears. *Construction Management and Economics*, **23**, 651–4.

Woolgar, S. (1991) Configuring the user: the case of usability trials, in Law, J. (ed.) *A Sociology of Monsters*, Routledge, London, pp. 58–99.

Woudhaysen, J. and Abley, I. (2004) *Why Is Construction So Backward?*, John Wiley and Sons, Chichester.