**Emerging hybrid practices in construction design work: the role of mixed media**

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# Abstract

Information technologies are used across all stages of the construction process, and are crucial in the delivery of large projects. Drawing on detailed research on a construction mega-project, in this paper we take a practice-based approach to examining the practical and theoretical tensions between existing ways of working and the introduction of new coordination tools. We analyse the new hybrid practices that emerge, using insights from actor-network theory to articulate the delegation of actions to material and digital objects within ecologies of practice. The three vignettes that we discuss highlight this delegation of actions, the ‘plugging’ and ‘patching’ of ecologies occurring across media and the continual iterations of working practices between different types of media. By shifting the focus from tools to these wider ecologies of practice, the approach has important managerial implications for the stabilisation of new technologies and practices and for managing technological change on large construction projects. We conclude with a discussion of new directions for research, oriented to further elaborating on the importance of the material in understanding change.

**Keywords: hybrid practices; mixed media; information technology; innovation; actor-network theory; ecologies of practice**

# Introduction

Construction, at least in the UK, is generally classified as a ‘low tech’ sector (Pavitt, 1984; Tidd *et al.*, 1997; Reichstein *et al.*, 2005). This is in some ways unsurprising, given the extent of on-site and craft-based work which compromises much construction activity. However, and perhaps somewhat against this received wisdom, construction work does embrace a wide array of information technologies across design, fabrication, construction and, increasingly, facility management. Computeraided design or drafting (CAD) systems, calculation tools, document management and knowledge management systems, project-based extra-nets and other IT-based collaboration platforms are established across parts of the construction process (Aouad *et al.*, 1998). The use of these various applications can be seen partly as a response to the extensive amount of information produced by and through construction activities (Higgin and Jessop, 1965), and partly as a response to continued government calls to improve the practices of construction as a sector (in the UK these include Latham (1994) and Egan (1998, 2002)). Such UK research and policy debates also have features in common with, inform and reflect related debates internationally, such as the discussions about productivity in USA construction

(Stokes, 1981; Teicholz, 2001; LePartner, 2007).

However, such a panoply of tools and applications has introduced new challenges at the same time as responding to existing problems. Across the global construction industry there is growth in the number of mega-projects (Flyvbjerg *et al.*, 2003) and an internationalisation of construction work (Mahalingam and Levitt, 2007). Information technologies play crucial roles here. Construction activity, displaced across numerous organisations and disciplines, requires high levels of information sharing between disparate actors. The challenges of inter-operability have been highlighted in a range of recent reports (Gallaher *et al.*, 2004; McGraw Hill, 2007) and are being addressed through a number of initiatives. The use of specialised tools within different domains results in a bewildering range and amount of information. This reflects the fragmented character of construction work, where information is produced within disciplinary or organisational domains. But it must also be shared outside of these specific areas, causing practical problems of finding and accessing relevant information, and more conceptual problems of interpreting domain-specific information outside of that domain.

Traditionally, paper printouts (drawings as well as other documents) are used to bridge these divisions, but this can lead to unproductive reworking of information between different tools (Love *et al.*, 1999) and can introduce errors, either through this re-keying process, or by not having the most relevant and up-to-date information. In response, combining the various digital tools into inter-operable and coordinated systems is heralded as enabling relevant information to be exchanged electronically with the effect of eradicating much of the waste and potential errors introduced through this re-interpretation of information. There is a long tradition of academic and practitioner work on integrated models (Anumba *et al.*, 2000), most recently focused around the discussion of Building Information Models (Eastman *et al.*, 2008;

Jernigan, 2007).

But attempts to assemble and implement inter-operable suites of tools to coordinate the whole of the construction process from start to finish have met with limited success. Though research demonstrates the advantages to using computer-based methodologies in practice (Hartmann and Fischer, 2005) there are a number of antecedent conditions required to take advantage of information technologies (Taylor, 2007) and pre-existing social structures may prove to be unexpectedly resilient to champions for change. One of the factors at play here is the dynamics of the software markets in which the developers providing these different tools are located, often as competitors (Harty, forthcoming; Whyte, 2003). But another important factor is the way that these different technologies have been unevenly and different incorporated into pre-existing practices alongside other non-digital forms of technology (such as paper and pens) and ways of exchanging information (for instance through paperbased drawings).

There are a number of studies of visual cultures, technologies and practices that shed light on the hybrid nature of practices in other context. In product development, Henderson (1999) draws attention to the visual culture of engineering and articulates the central role that visual representations play as a reason for engineers resisting new ways of working that change their practice. In court trials, Lanzara (2007) notes how the introduction of a digital tool, in this case a video of the proceedings, does not simply replace one practice with another but leads to a hybrid ecology through a process of ‘re-weaving’ of the fabric of the practice. In both these studies new ITbased ways of working supplement and alter non-IT based work patterns rather than completely replacing them. This paper examines in more detail this issue of the persistence of non-IT based ways of working in construction, positioned around several questions, which draw on our readings of studies of visual cultures and

practices:

* How are non-IT materials currently used within the practices of construction?
* What are the implications of switching to electronically mediated practice?
* When this shift is attempted, what hybrid practices emerge around the new technologies?

The next section outlines the theoretical and methodological approach adopted to address these questions. It draws on insights derived from actor-network theory regarding the role of material objects in the (re)production of practice. Following this, and a brief outline of the methodologies used to collect the data discussed, come three vignettes, derived from two studies of the implementation of new design tools on a very large construction project. The main emphasis of the empirical discussion here is in exploring the tensions between existing ways of working and the introduction of new coordination tools, and in analysing the new hybrid practices which emerged during the implementation process. In the final section of the paper we then articulate the managerial implications of this perspective for management of technological change on construction projects.

# Practices and Material Artefacts

A key component of the conceptual and methodological approach adopted here is the consideration of the roles and effects of material entities within accounts of practice. Such accounts act as useful counters or supplements to those which focus only on social and/or structural aspects of interaction. Within these objects or material artefacts are sometimes incorporated, but arguably only in an passive sense; they are seen as mirroring or reflecting social distinctions (Bourdieu, 1984), as a backdrop or stage proving part of the contexts in which social interactions are played out (Goffman, 1971), or as ‘material levers’ or resources which are manipulated by knowing individuals (Giddens, 1984). However, there are alternative approaches which position material artefacts as a more active constituent within the field of practice and the area of science and technology studies (STS) has promoted the material to a much more prominent role. Within this literature, actor-network theory (ANT) in particular has positioned the material on an equal footing with human

actors.

Actor-network theory places the ‘actor-network’ at the centre of understanding. Actor-networks are characterised by continual transformations and (re)configurations of actors and artefacts occurring through interaction. Practices can be seen as the performance of these actor-networks. The co-production of non-human artefacts, actors and practices are framed as sets of associations being formed and held together or pulled apart and reconfigured. This process has been called ‘heterogeneous engineering’ to denote the involvement of a variety material as well as human actors (Law, 1986; 1992).

But actor-network theory has also been criticised for taking the role of the material too far, by arguing for a methodological symmetry (Callon, 1986) which attributes to human and non-humans the same status as actors. This principle is a development of a concept originally mobilised within the sociology of scientific knowledge (SSK) literature to denote treating ‘true’ and ‘false’ claims about scientific knowledge alike.

This usage was positioned against the idea that objectified approaches should be used to explain scientific truths, with more sociologically-oriented explanations limited to understanding how false clams come about (Bloor, 1976). Callon extends this, into treating human and non-human entities alike.

Latour has suggested that this principle of symmetry is perhaps the “most important philosophical discovery” (1999: 283) of this perspective. However, others have refuted this promotion of the material to the position of actor. Instead, they argue that symmetry is a misrepresentation of what is in fact a purely socially constructed account of the material (Collins and Yearley, 1992) or that a distinction must be made between the human actor, replete with intentions and goals, and the material which cannot have such things of their own (Pickering, 1993).

This tension between symmetry and asymmetry can also be found within the ANT literature. The concept of delegation (Latour, 1992) describes how the intended actions of human actors are displaced or transferred onto material artefacts; one example is the door closer which replaces the human actor, and action, otherwise required to close the door. This is a plausible account of how the material might be endowed with agency or the capacity to act, but also retains the suggestion of some difference between how humans and the material act. Suchman argues that delegation implies;

“other actors standing just offstage for whom technologies act as delegates, translators, mediators; that is, human engineers, designers, users, etc (Suchman, 2000: 7)

Although complex and possibly irresolvable, these debates do serve to point towards the importance of including the material when considering how practices emerge and are transformed. Considering the delegation of agency to artefacts such as computer systems and software allows the inclusion of the effects and roles of the material on forming networks, but, following Suchman’s argument, without losing sight of the ontological differences between humans and artefacts.

When thinking about how new technologies becoming incorporated into practices, the concepts of *actor-networks* and of *delegation* provide useful analytical tools. Tracing the associations and configurations of actor-networks directs the researcher to the social aspects of interaction – the ways that people interact and the expectations, ideas and conventions which inform them. But the actor-network also emphasises rather than excludes the active role of material artefacts in the performance of practice. By positioning this agency as attributed through delegation, some asymmetry or differences between humans and non-humans can be retained, without down-playing this role of the material. The approach has begun to be discussed in the context of the construction industry (Harty, 2005; 2008).

Investigating why some practices around specific artefacts (such as paper) persist despite attempts to remove or replace them, might usefully take account of the particular roles these artefacts play. This might be difficult when purely *social* accounts of practice are mobilised. But by positioning practices as emerging from or constituted through actor-networks of interconnected human and material agents, *socio-technical* accounts of practice can be developed, which consider their hybrid constitution. It allows more ecological or inclusive explanations of emerging practices to be produced (Star and Greisemer, 1989), which consider not only social and structural aspects, but also material components. In addition, networks can be traced beyond immediate local contexts, allowing consideration of wider professional, disciplinary and institutional effects on emerging practices. Building on these two aspects, the remainder of this paper elaborates on the constitution and emergence of such ‘ecologies of practice’ during the design and construction phases of a large construction project.

# Empirical case and methods

The empirical material discussed below is derived from two detailed cases studies of the same project – the construction of an airport terminal near London, UK. This was a very large and complex project, with a value of £4 billion / $6 billion. The client had a commitment to both delivering the project on time and on budget, and to utilising emerging technologies to co-ordinate the whole process, from design through construction to eventual facility management. This involved not only the production of the terminal’s design on computerised systems, but also the coordination of this heterogeneous data across inter-operable platforms, and retention of all design and construction information on a cross-project document management (DM) system.

The key to this was the fostering of a ‘single model environment’ (SME); a shared and coordinated digital repository of all project information. The idea of the SME hinged on the idea that if the project could be build virtually first, this would identify any problems before on-site work began, and costly errors were made. This process, known as ‘clash detection’, would integrate all of the separate aspects of the design (e.g. structural, architectural and building services elements) into a single 3D model to check for spatial inconsistencies. This would be supported by the DM system which would act as the single mediator for the creation, exchange and revision of project data, and provide a full accountability trail for tracing problems encountered. It is worth noting that the SME can be seen as and early incarnation and as synonymous with the now much more widespread notion of the BIM or building information model (see e.g. Eastman *et al*; 2008).

In addition to positioning these technologies as a way to improve coordination across the construction process, the client also saw digital coordination as a way to eradicate non-digital technologies from these practices. By placing these technologies at the centre of both practices of ‘doing’ design and construction, and of interacting across the project, the need for paper printouts, cardboard models and so on would be removed, in itself allowing considerable cost savings. But, as will be discussed, this shift also would require significant changes in practice for the designers, engineers, and drafters on the project.

The technological requirements to enable these new coordinative techniques were significant. Not only was a large range of specialist design and drafting software required, but also these artefacts had to be inter-operable to allow coordination across the whole project. To mitigate the potential problems associated with such an ambitious vision within an already challenging project, a unique agreement was drawn up between the client and the framework partners, where the client retained much of the risk involved. This was intended to allow the partner firms to concentrate on embedding the new tools without fear of costly problems and delays. Also, the client co-located much of the inter-organisational staff in offices by the construction site, to encourage interaction across the project’s staff.

Both cases were closely focused on investigating the particular functions that technologies were being utilised for, in terms of the coordination of a highly complex project, and the attempts to reconfigure or transform current practice through new technology implementation. The first empirical study of this project was conducted by the first author in 2001-2. It consisted of broadly ethnographic research, using observation of staff at work, attendance of project and team meetings, informal discussions, documentary analysis and, towards the end of the research, 23 interviews.

In total, approximately 50 days were spent at the project’s co-located offices, spread in three to four day blocks. The interviews were largely designed to capture, and explore further, the insights from the observation-based aspects of the research. The second study was conducted by the second author in 2005-6, and was mainly interview based, with more than 60 interviews conducted (36 transcribed, 24 informal) alongside access to project documentation. Each study was highly explorative, using interactive processes of data collection, analysis and theory building. Each study was also in itself focused around questions about the temporal processes and practices involved, and the three year gap between the studies adds further longitudinal insight.

Below, we offer three vignettes taken from these larger studies. Throughout the discussion, the central emphasis is on the sorts of practices that were being performed on the project, how various agents were attempting to transform these practices to incorporate new technologies and switch media to a digitally-coordinated process, and what came out of this. In line with the position outlined above, particular attention is paid to the ways that various material artefacts were incorporated into both existing and emerging socio-technical ecologies of practices.

The first two vignettes discussed here come from the first case study, conducted during the detailed design phase of the project. The third comes from the later study, when construction activity was well underway, and concentrates on one particular aspect of the project – the design of the main terminal roof.

# Exploring ecologies of practice

## 1. Hybrid practices in designing and drafting

A key aspect of this translation or switch to a digitally-coordinated process was the requirement to produce the complete project design using three dimensional modelling techniques. This was necessary to allow full spatial coordination of the information from various disciplines and groups across the project. But the traditional and expected method of producing and sharing design information is through 2D plans and schematics.

As implementation began, and the notion of digital coordination was communicated to project staff, immediate problems became apparent over the reliance both on 3D modelling techniques and on an electronically centred process. Team managers, engineers and designers and CAD drafters were sceptical of any attempts to remove

2D drafting, and other non-computerised 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.” (CAD drafter)

These existing practices were very robust in the face of attempts to move them towards 3D based practices. Although they included considerable use of CAD tools they also incorporated many non-digital artefacts. This was very apparent from observing designers, engineers and drafters at work.

Indeed, one of the most striking features of the project’s design offices (and many other design offices) was the range of different materials on display. There were of course many computer terminals being studious interrogated by staff. But there were other artefacts; cardboard models of bits of the roof design, a range of both colourful and technical printouts, printers whirring away. As staff worked, a variety of materials were utilised, including paper and pen sketches and 2D CAD systems, with designs going through several iterations as they became gradually more fixed and certain:

“all that [designing] 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.” (Detail architect)

This was definitely borne out in the project’s offices. Desks were littered with paper printouts and hand-written notes and sketches, and these artefacts were readily exchanged between and modified by different staff. This arrangement of artefacts was rendered even more striking given the relatively small amount of desk space that was given to staff; the space was laid out in accordance with imagined practices which dispensed with paper, and were centrally computer based. However, this actually resulted in chaotic spaces where large format printouts and piles of paper struggled for space with keyboards and mice. This also spilled out onto shared spaces around the offices.

The utilisation of various non-digital materials for designing has been discussed before, and is well summed up by Henderson’s opening gambit of ‘I can’t think without my drawing board’ (Henderson, 1999: 1) But even for the more technical aspects of producing digital models non-digital materials were consistently used. For instance, 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.” (CAD drafter)

One drafter was observed measuring dimensions from a print-out with a ruler. When asked about this, the response was that paper was much more ‘intuitive’ in terms of assessing details like dimensions, and it was usual to do this rather than deduce them directly from CAD models on a computer screen.

In acknowledgement of the robustness of these existing practices, 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, and the use of 2D CAD and of non-digital materials was at least tolerated, if not wholeheartedly accepted by the project’s management.

### Discussion

It is revealing to think about the ways that the practices of designing and drafting were distributed across numerous actors and artefacts. Tracing or following these practices across the actor-networks which constitute them led to a wide range of heterogeneous entities. A robust social division of labour was revealed between the activities of ‘designers’ and ‘drafters’. This was most notable when describing the way ‘designs’ were handed over to drafters. While in this vignette drafters were involved in drawing up the designs in CAD formats, the distinction between designers and drafters has persisted since before the advent of CAD technologies (e.g. see Lee, 1991). This is a clear example of aspects of pre-existing conventions and ways of working persisting despite changes in technological artefacts.

For both designers and drafters, practices were also spread across different artefacts. As one might expect, pens, paper, and physical models all played central parts in practices of designing. But in addition the more ‘technical’ aspects of producing the CAD models themselves also showed the integral role of rulers, printouts and pens. This leads to the perhaps counter-intuitive observation that the very practices of CAD work are as reliant on non-digital artefacts as they are on computer systems and software. Without these other materials, it is difficult to imagine what the practices of either engineering designing or computer drafting might look like.

Similar conclusions can be drawn regarding the ways that engineering designers and computer drafters interacted; sometimes a focus might be on models on a computer screen, but more often revolved around mutual exchange and revision of paper-based representations. Even when a digital model was the focus of interaction, other artefacts were also involved. The ecologies of practice observed were hybrid both in terms of their human and material constituents, and in terms of the incorporation of new and localised factors (such as a drive for digital coordination) with existing conventions and divisions of labour.

It is, then, perhaps no wonder that a move towards wholly digitally oriented methods of designing, drafting and collaborating was not entirely successful. These efforts signify fundament alterations of divisions of labour as they re-delegate the work that paper and other artefacts did onto the digital tools, work that included mediating and participating in the interactions between people as well as the actual formulation and refinement of designs and models. But we might argue that these practices to be changed were not bounded or contained solely within human actors, but were rather performed through, or emerged from, the interconnections between engineering designers or computer drafters and a range of artefacts. This meant that moving towards a digitally-oriented process was just not a simple case of stopping using some passive artefact and substituting another in its place. In fact, these practices under scrutiny were distributed across material - human boundaries in complex ways which evaded any straight forward substitution and (re)delegation as anticipated by the project’s management.

This vignette shows how the delegation of actions to IT-based tools might be resisted where such delegation significantly challenges existing ecologies of practices – themselves drawing on well-established professional and experiential factors as well as more immediate and localised contexts. The different ways that materials and media participate in design and drafting practices mean that they are not easily interchangeable, nor can the hybrid or socio-technical quality of existing practices be neatly separated into human and non-human components. It also demonstrates a complex and heterogeneous distribution of practice beyond simple utilisation of material artefacts as tools or add-ons to a human centred process. In this case, changes in artefacts can threaten the existing practices and wider professional identities of engineering designers and computer drafters. It also goes some way towards providing a potential explanation for the persistence of supposedly ‘outdated’ artefacts and throws light on the challenges of bringing about wholly IT-based design practices at a local level. We now turn to the coordinative challenges across the main firms involved in the project by considering the document management system.

## 2. Escalating ecologies of practice for coordinating document management

Another of the essential criteria for digital coordination on the project was the use of a document management (DM) system. This was necessary to ensure that design information was correctly produced and centrally held, shared and updated, and so that staff were always working on the most recent versions of documents. But once again there was intense resistance against it from users:

“to file anything you have to go in, you have to put all these codes in, and we said this is nonsense because we normally sling it in a drawer… it was too much effort.” (Head of engineering)

“we had a big issue early on in my time here where all of the drawings resided outside of the system – none of them were in [the DM system] and everyone was saying ‘yes they are, yes they are’… but there was no

[single] model, it didn’t exist.” (Services team leader)

“[the DM system] is just utterly indescribably crap. An example - the other day I started searching for a document, had a 10 minute conversation at which point the machine reported that it couldn’t find it… its not worth it – it stalls the machines to the point where you can’t do anything else – I actually timed it and it took 6 minutes to open a window.” (Services engineer)

In response to these problems, the project’s management instigated a number of initiatives. These included writing documents outlining step by step instructions on how to:

“verify compliance with Document Management policies & practices, including verifying compliance of document control procedures operated within the various teams, using surveillance and audit techniques.” (DES02 project document)

as well as extensive training in the correct conventions for both producing information and using the DM system:

“When a member of staff comes in they need to be running through what is expected and one of the things is how they should use [the DM system], where they should be putting information and also following the project procedures.” (IT support worker)

These actions can be seen as a sort of ‘plugging’ or ‘patching’ in order to support or bolster attempts to align individuals with project-wide processes of document management. Where the DM system was not being used (either in the correct manner, or at all) different associations were assembled; for example between passing DM training and getting access to the project’s IT system or between following standard practices and being able to access project information. But interestingly, although this was all designed to reduce practices of information creation and sharing to a coherent set of DM mediated processes, attempts to bring this about in fact continually increased the range of people and artefacts involved in these practices.

Whenever one escape route out of using the DM system in the specified manner was closed off, others were opened. As the requirements for using DM increased, so did the number of files being exchanged via disk. When this was prohibited, they were emailed. This route was also closed off, and whole machines, complete with unofficial software, were smuggled in, again to allow users to work outside of the DM system. The standards document itself was subject to constant revision. The training and testing requirements became so strict that some staff, especially those that were not CAD drafters or sophisticated IT users, were locked into a continuous cycle of taking and failing the tests, which meant that they couldn’t access any of the information on the system, or create and edit documents.

The final act of patching was the sending of ‘document controllers’ from IT support to work with specific design teams across the project:

“you need to make sure that they [the users] are adhering to the process, definitely. Most of the delivery teams do now have a document controller to keep an eye on things.” (IT support worker)

This did result in greater, if not total, use of the DM system, but the resources, both human and material, required to make the system run also escalated, placing further burdens on project and support staff:

“There’s plenty of subversion… We have people who work offline [outside of the document management system] to compile lots of data that is always sketchy, and then we give it to dedicated CAD draftsmen who do nothing else but put stuff into [the DM system].” (Architect team leader)

“we’re playing ball with it – but we’re having to allow more time to do what we were doing… the efficiency is diabolical.” (Detail architect)

### Discussion

This case neatly demonstrates some of the unforeseen consequences of, and complexities involved in, attempts to engender new practices. Like the digital design technologies discussed above, the DM system was unable to effectively carry the intentions of project managers, and new electronic practices of information management to users. Aspects of existing, non-digital practices remained strong, but became incorporated into emerging practices which continued to circumvent ‘proper’ utilisation of the DM system. In common with design and drafting activities, printouts, disks and emails were central to these emergent hybrid practices. It is also important to note that these deviations were largely taken with the intention to carry on working on the project rather than undermine it; many staff felt that to adopt these DM practices also meant that the work of designing the terminal would be significantly impeded.

The case also shows how, over successive iterations, the practice of document management became more and more distributed over numerous heterogeneous entities; DM systems, PC’s, standards documents, training programs, tests, designers, drafters, document controllers. Dynamic actor-networks were being transformed and extended, as all of these entities were enrolled into an increasingly complex ecology of people and artefacts. This eventually began to fulfil the intentions of the project managers, but in doing so became unwieldy and resource intensive.

This case provides some interesting insights into processes of delegation. We might see the case as one of a failed attempt at delegation; the requirements of the project’s management were not effectively delegated onto the DM system; the artefact alone was then unable to bring about desired changes in practice – it was resisted and rejected by project staff. But we can also see this as as an on-going test; a ‘trial of strength’ (Latour 1988) between this desire and the configuration of the networks into which it was introduced. A process of ‘plugging’ and ‘patching’ emerged, where routes for resistance (such as using printouts) were successively identified (by the users) and closed down (by the project managers and IT support). Eventually, a set of practices stabilised which enabled DM to be used, but not in an efficient way, and these practices certainly looked somewhat different to how the project’s management envisioned them initially.

Again some practical implications are clear; notably in that the resources required to bring about digitally coordination practices were much greater than expected. This vignette shows how the ‘plugging’ and ‘patching’ that is required to develop and sustain the ecology of practices. Such plugging and patching eventually resulted in a workable process, but one that was very inefficient when compared to usual methods of exchanging information. Elsewhere, Whyte (2008) also describes similar temporal dynamics of this breakdown in the document management system and the work that is done to revitalise the system. This escalation led to other practical problems as ways of circumventing the DM system were closed off or patched, most notably in setting high entry standards for getting onto the DM system. The complex training and tests which staff had to undertake led to individuals with essential (non CAD or DM based) skills required for the project being themselves excluded from the sanctioned DM practices. Where the first vignette centred on the specific practices of engineering designers and CAD drafters, here the focus is on attempts to coordinate information horizontally across the whole project. But the outcomes are similar; a switch to purely electronic coordination in fact resulted in an increasingly complex ecology of objects and people. The final section looks at a further set of interactions on the project; the vertical relationships through the supply chain.

## 3. Ecologies of practice for design and delivery: supply-chain coordination

The DM system and SME were available to all of the first-tier suppliers. However, other suppliers – the fabricators and temporary works designers – did not have access to these systems. In highlighting the engineering design work that was done on the roof sub-project, this final vignette describes the non-digital practices that were used to discuss engineering design and coordinate work in a way that involved the whole supply-chain..

The very practices of designing, and of making design decisions on this project were inextricably connected to the manipulation of models. This decision-making and modelling took place across a range of media, and scales:

“chronologically there were 1: 200 models on roof forms. There were 1: 50 models of half the roof, once it became symmetrical, and mirrors; there were 1: 20 beginnings of the abutment. There were 1: 20 of the abutment and half the roof; there were 1: 10, 1: 5, 1: 2, of the nodes.” (Roof

architect)

In contrast to the logic of the SME, where data is created once and reused, here data was created multiple times as designs were tested and refined; and their

constructability was discussed in increasing detail. The practices of designing the roof incorporated a range of actors, and a range of artefacts, from rather low-tech plasticine to sophisticated prototyping equipment. These were all used to ‘play’ with different designs in different media:

“it’s not about digital technology at all, the playful aspect of it, (the architect] did a lot of making Plasticine models and cardboard models and they were very, very useful.” (Engineer)

These physical models were important to the whole team in coming to a shared understanding of the complex structure. This was particularly important on the roof, where the challenges of the erection sequence and temporary structure affected the design of the permanent structure. Fabricators and temporary works designers, though not collocated with the first-tier suppliers, had crucial roles in the design process. The non-digital models became a point of reference for conversations about how things fitted together and worked. The engineer said that:

“on our models of it, you see the framing on this side of the building and then you also see the framing on the other side of the building and it makes you feel there’s something physical in front of you, you can…you can perceive it more, its sort of its there isn’t it ...” (Engineer)

This ability to ‘see’ the design as it develops is something that is lost when prototypes and modes exist only in the virtual world, contained within computer hard drives and small screens. Indeed, similar arguments have been mobilised by CAD managers over the replacement of drawing boards with CAD workstations, where the immediacy of the ability to view work-in-progress is lost. Hence reliance solely on virtual models, even when these are three dimensional, are clearly seen as constraining design practice or requiring translations into different ecologies of practice. In the work that was done on the roof sub-project, digital models were used to generate new nondigital models and vice versa with 2 model-builders and one digital modeller working as part of the team.

The physical presence of these models had benefits to the team, both in terms of their discussion and in terms of enrolling other actors, such as client managers, into their network of practice:

“that was another valuable aspect of these physical models. [the client manager]’s office is at the end of the office and […] so he has to walk past this every day and he sees it and so even without making an effort to communicate the design to him, he’s seeing the design every day as he walks past it and they’re aware of what’s going on. It’s a very powerful thing.” (Engineer)

### Discussion

This vignette shows how vertical integration through the supply-chain was dependent on the shared understandings that were developed around a range of physical models. These physical models played an important role not only in allowing the designing of the roof to be undertaken – a hybrid and iterative process also involving virtual models - but also in engaging actors outside of the SME, such as fabricators and temporary works engineers. Tracing the network around the design of the roof led through these physical models to such external actors; the models functioned to align these actors within this ecology of practice. It was the non-digital models that enabled the temporary works designers and fabricators to understand the overall roof design as well as giving the client managers an understanding of what was going on.

In this sense, the intentions of the designers were not delegated onto virtual models and a digitally-based process, but incorporated into a series of non-digital models, using a range of media – paper, plasticine, cardboard. Again, the practices of design are distributed over these different artefacts and draw heavily on pre-existing expectations about, and ways of, designing and communicating design ideas and intent. Virtual models were used, but only as a part of more established practices of doing design.

When considering why these design intentions were not delegated solely onto virtual models, it is not just a case that hybrid ecologies of practice are inevitable, or that it is highly difficult to transform existing practice; it is important to note that overwhelmingly the participants emphasised the physicality of non-digital models –

“it’s not about digital technology at all...”, “you see the framing of it...”, “he’s seeing the design every day as he walks past it...”. Whether for playing with different designs, for seeing (quite literally) different perspectives, for sharing ideas with others within and without the project and even for demonstrating progress to the project’s clients and management, the physical seems to have some aspect of tangibility that virtual models do not.

Given this, it is interesting that the roof sub-project was remembered as an exemplar in the use of the Single Model Environment for co-ordination with other sub-projects. Of course, this is largely due to the result – a satisfactory roof design. But arguably because there was no attempt to replace or substitute the physical for the virtual, and the engagement with physical artefacts that constitute design work was maintained, a successful outcome was achieved. Virtual models and modelling were incorporated into emerging ecology practice, but not at the expense of other forms of modelling. There was no real Latourian trial of strength as seen in the previous case of implementing document management; rather the virtual was incorporated as a part of existing ways of working.

# Summary of cases

Across the three vignettes discussed, various artefacts play central roles in the practices of designing and drafting; co-ordination horizontally across the project; and co-ordination vertically through the supply-chain. These do include digital technologies such as CAD packages, but also incorporate paper, pens, rulers and plasticine. Without these multiple materials, it is difficult to imagine what the practices of design and drafting might look like, not only for us in analysing our data, but also for the engineering designers and computer drafters themselves. Over time and across these different studies, multiple entities were continually mobilised as practices were performed. These not only incorporated local actors and artefacts, but were also shaped by wider, institutionalised notions of disciplinary identity and existing practices (along with constituent material entities). It is not easy, or even possible, to describe what was happening within these vignettes without recourse to an ecological and hybrid perspective of practice.

This sets us a significant challenge in any attempt to enrol stakeholders and improve performance through the implementation of new information technology solutions in large projects. The notion of practices as emergent and performed is important as it serves to draw attention to the institutionalised and processual nature of practice. The second vignette in particular demonstrates the dynamic, continual shifts in practice emerging as different artefacts and actors are drawn into ecologies of practice. It also helps to underscore unforeseen aspects of these changes; attempts to limit the artefacts embedded within practice actually resulted in more and more artefacts (and actors) becoming engaged in designing and drafting.

Although the narrative and eventual end point of each vignette is different, we see similar sets of processes occurring within them. Specific *outcomes* are not certain or generalisable; they are dependent on the particular characteristics of existing ecologies of practice, and the unpredictable implications new entities may have upon them. But the *processes* through which ecologies of practice are shaped and shifted consist of iterative negotiations across different sets of associations, as new ideas, actors and artefacts are introduced. In each of the vignettes these processes led to hybridity, with digital and non-digital materials enrolled as part of ongoing practices. It is at the level of understanding these processes, rather than their outcomes, that this research makes its contribution.

# Managerial Implications

By shifting the focus from the tools to the ecologies of practice, this research has important managerial implications for the implementation and stabilisation of new technologies and practices and for the management of technology in large construction projects. We highlight the need for management consideration of the heterogeneous constituents of ecologies of practice and their inter-relation. An activity which may at face value look like a straight-forward substitution of one set of technologies (e.g. paper) for another (i.e. digital technologies) neglects the robustness of existing configurations and the possible significant repercussions such activities imply. The more that change initiatives challenge existing ecologies of practice and ways of working, the more likely they are to be resisted; the more likely trails of strength will ensue. This is not, of course, about expecting broad and irrational resistance to change, but to consider the inherent challenges in taking one set of practices, developed over time and distributed across a range of actors and artefacts, and translating them into something else. Positioning practice as something out with the single human actor locates the challenges of implementing new technologies and practices as something other than individual resistance or unwillingness to change.

Acknowledging the heterogeneous and inter-subjective (i.e. across multiple people and oriented around interaction) character of practice places the emphasis more on aligning and accounting for the ways these practices are located across a variety of material as well as human components, and within a context of intersecting institutional and professional expectations and conventions. We would argue that the key lies in attempting to understand what these are, ands to work towards

collaboratively shift practices, rather than setting out particular end-points and trying to enforce them.

The difficulties in ‘switching media’ and the disruptions to practice this can cause have been noted elsewhere (Lanzara, 2007). But we might go even further; it is not possible to switch media, without also reconstituting practice; artefacts cannot be changed without also fundamentally changing the practices they in part constitute. This is a recognition of the integral role of the material in practice; if practice resides solely in human actors, and artefacts are merely passive, it would perhaps be a much simpler job to substitute them for alternative tools. But this is not the case; practices are hybrid and distributed across heterogeneous entities in complex ways.

More concretely, project management, in setting the agenda for transforming practice, needs to provide a clear vision for technological change but also to develop and pay attention to the mechanisms for that change, and to its implications for current ecologies of practice. Recursive and escalating processes of plugging and patching are time and resource intensive for management and designers, and, as in the case of document management implementation, can lead to practices which are unwieldy and inefficient. The physicality of non-digital models seems to be important not just in the practice of design, but also in showing progress, and tangibly demonstrating the state of on-going work. Virtual models, locked within hard drives and accesses via computer screens, seem to lack this immediacy.

So successful translation of ecologies of practice involves recognition of and support for clumsy or partial hybrid solutions, and a commitment to considering the implications of attempts to dissociate one set of connections and form others. This also has to be considered alongside some of the recurring challenges construction work presents. The nature of project-based work means that particular constellations of actors and artefacts are always temporary. At an organisational level, construction firms have to manage multiple projects, often utilising different technological platforms. Changes to and revisions of artefacts such as software often occur on shorter timescales than the lifespan of specific projects. These issues all have implications for managerial decisions of whether to implement new technologies, or stay with existing configurations. When the potential for the resource intensity of such change initiatives are also considered, the need for an on-going and iterative approach to managing change, rather than the setting of fixed end points becomes all the more necessary.

# Conclusions

Given the significance of ongoing work to develop Building Information Models on both sides of the Atlantic, our cases provide a lively reminder that technological solutions are rarely that – solely technological. Rather, we suggest here that technologies are incorporated into existing ecologies of practice, which already might utilise a diverse range of material and digital artefacts. Further, it is through these ecologies that the work of designing, drafting and coordinating gets done.

The term ecologies of practice is itself significant. As a concept it denotes the heterogeneous and distributed entities which constitute practice. It is these entities which form the ‘building blocks’ which, once associated together, form practices. But further, it encapsulates other concepts such as actor-networks, hybridity, delegation and ‘trails of strength’ and it is through the mobilisation and use of these concepts that the ecologies themselves can be traced. Ultimately, this leads us to position technological change as a negotiation between existing and new practices, and to position resistance as something which is not grounded within the individual, but as distributed across actors and artefacts. These are important insights, and help to explain why attempts to switch media or change technologies are not simple substitutions, but can severely disrupt, transform or dislocate the very activities which are central to performing design and construction work.

To revisit a question posed at the beginning of this paper, what hybrid practices emerged? The vignettes describe a number of such practices; the use of physical artefacts for the production of digital models in the first case, the escalation of the ecology of practice around using DM that resulted in compliant but inefficient use in the second; the use of digital alongside physical models for exploring designs and communicating with other actors in the third. But although outcomes are uncertain, a central contribution is that the processes which produced those outcomes have common characteristics. These characteristics are the iterative negotiations across different sets of associations, as new ideas, actors and artefacts are introduced, which in all three cases involve a set of digital and non-digital materials across a set of distributed practices.

Taking this forward provides some new directions for research, given the utility of concepts of actor-networks and of delegation as analytic tools. The concept of ‘actornetworks’ maintain the focus of research and analysis on the material as well as the social, and on tracing the dynamic connectivites between entities, rather than positioning them as discrete and bounded. The concept of ‘delegation’ provides both a tool for interrogating how various artefacts – physical and digital - are endowed with the capability to act alongside humans, and a reminder to trace back the intentions and goals which are delegated onto them. We introduce the terms ‘plugging’ and

‘patching’ to describe the kind of work that is done to sustain practice when the actions that have been delegated to technologies alter and do not adequately support the overall ecology of practice.

But more research is required to further understand the significant role that technology plays in global projects, and especially the ways that construction firms learn about IT use from project to project. What we can advocate is that research and researchers can use these tools to follow and map how ecologies of practice transform over time, and across organisations, and across projects. Who, and what, is being incorporated into negotiations around changing practices or technologies? How are these negotiations undertaken in specific contexts? What institutional, professional or experiential perspectives do they draw upon? These are the sorts of questions that can help the researcher to empirically trace the dynamics of practice.

The concept of ecologies of practice is highly useful for understanding how IT use is situated across actors and digital and physical artefacts and within wider cultural and institutionalised practices. It provides a conceptual framework for the further exploration of how hybrid practices emerge, and for supporting these change

initiatives within construction.

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