The role of media in construction design work and ecologies of practice

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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 that exist between existing ways of working and the introduction of new coordination tools. We analyse the new hybrid practices that emerged, 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 the tools to ecologies of practice, the work has important managerial implications for the stabilisation of new technologies and practices and management on large construction projects.
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. Computer-aided 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))1.

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).

1 Such UK research and policy debates 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).
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 paper-based 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 IT-based 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. This is broadly oriented towards a practice-based approach, and more specifically uses 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 (£4 billion / $8bn) 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.
The ‘practice turn’

The practice turn in organisational studies is perhaps better described as a diverse collection of theoretical accounts which share a common proposition – that the proper field of inquiry for understanding what organisations and individuals do is the field of practice. Moreover, the social world is broadly considered:

“a field of embodied, materially interwoven practices centrally organised around shared, practical understandings.” (Schatzki et al., 2001: 3)

There are two aspects illustrated in this definition which can serve to differentiate practice-based accounts from others. The first is the embodied nature of practice. Although the individual and individual cognition are important, practices are extra-individual; they emerge from the efforts of multiple actors to develop shared understandings and activities through interaction. Practices are not developed by individuals in isolation, but through largely tacit, rather than explicit or codifiable, processes. A strong emphasis is therefore placed on seeing organisational learning and knowledge as emerging from the on-going (re)production of practices (e.g. Orlikowski 2002, Nicolini et al., 2003) within specific contexts.

The second aspect is an acknowledgement of the role of material artefacts in mediating and enacting practices. This intuitively makes sense, as practices rarely involve only human actors, but rather incorporate a plethora of material artefacts. However, within practice-based approaches there is no consensus over precisely how much importance, influence and agency is attributed to such artefacts, and the attribution of some sort of agential capacity to the material can lead towards some complex ontological and epistemological debates. It is to these we (briefly) now turn.

Material artefacts, agency and practice

Adopting a practice-oriented approach and situating the material as a central part of practices acts as a useful counter or supplement to accounts which focus only on social and/or structural aspects of interaction. Within such approaches, 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). This emphasis on the (re)production of actors and objects through interaction has led to actor-network theory being positioned by some as part of the broader ‘practice turn’ (Bresnen, 2007).

But actor-network theory has also been criticised for taking the role of the material too far, by arguing for a methodological symmetry\(^2\) (Callon, 1986) which attributes to human and non-humans the same status as actors. Although Latour has suggested that this principle of symmetry is the “most important philosophical discovery” (1999: 283) of this perspective, 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 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

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\(^2\) It should be noted there that the notion of symmetry discussed here in terms of methodologically treating human and no-human as actors alike should be distinguished from the concept originally mobilised within the sociology of scientific knowledge (SSK) literature to denote treating ‘true’ and ‘false’ claims about scientific knowledge alike. This latter 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 claims come about (Bloor, 1976),
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 first author’s work explores this approach in the context of the construction industry (Harty, 2005).

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 ‘ecologies’ (Star and Greisemer, 1989) of interconnected human and material agents, more inclusive socio-technical accounts of practice can be developed, which consider their hybrid constitution. Building on this, the remainder of this paper examines current and emerging practices 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 / $8 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 take all of the separate aspects of the design (e.g. structural, architectural and building services elements) and integrate them 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.

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

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3 It should be noted that the concept of the SME can be seen as an early incarnation and as synonymous with the now much more widespread notion of the building information model (BIM).
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.

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 as part of a team of researchers involved in studying the project in 2005-6, and was mainly interview based, with more than 60 interviews conducted (36 transcribed, 24 informal) alongside access to project documentation. 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. Also, each 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’, and the practices that these enabled.

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.

**Agency, practice and artefacts**

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 studiously 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.

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 led to a wide range of heterogeneous entities. A robust social division of labour was evident between the activities of ‘designers’ and ‘drafters’, but for both, practices were also spread across different artefacts. As one might expect, pens, paper, cardboard, glue; these all played central parts in practices of designing. But in addition the more ‘technical’ aspects of producing CAD models 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.

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 fundamental 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 can be resisted where such delegation significantly challenges existing ecologies of practices. The different ways that materials and media participate in design and drafting practices mean that they are not easily inter-changeable, nor can the hybrid or socio-technical quality of existing practices be neatly separated into human and non-human components. This vignette demonstrates a complex and heterogeneous distribution of practice beyond simple utilisation of material artefacts as tools or add-ons to a human centred process, where changes in artefacts can threaten the existing practices and 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… it’s 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.” (DES-02 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)

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, print-outs, 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. All of these entities were enrolled into an increasingly complex ecology of people and artefacts, which eventually began to fulfil the intentions of the project managers, but in doing so became unwieldy and resource intensive.

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 sustain and develop 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 document management system and single model environment 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 visual and material practices that were used to discuss engineering design and coordinate work in a way that involved the whole supply-chain.

The roof sub-project became a focus on attention in the second of the research studies because it was remembered by managers, not only as an example of excellent practice but also, as a good exemplar of the use of the single model environment. The study did find strong use of modelling in decision-making on this sub-project, but this modelling was physical as well as digital. The architect remembers that:

“I think there was a point again, when we were all [collocated at site] and a lot of people saw that the roof was going to be built first, and they saw that there was a level of seriousness within the roof team - the contractors, the engineers, and the architects, and that was, sort of manifested in being able to decide. You can’t decide as an architect until you’ve built a model, physical or otherwise.” (Roof architect)

The use of modelling in decision-making was central to the engineering work. The very practices of designing, and of making design decisions on this project were inextricably connected to the manipulation of models, and that 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. The, the 1: 5 we often did in plasticine, so one model served for five or ten times. In total there, there must have been 300 models made. Then early on, with the 3D we went to… I think we went to (university] to do a prototype, a wax prototype process.” (Roof architect)

In contrast to the logic of the single model environment, where data is created once and reused, here data was created multiple times as designs were tested and refined. 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. When asking what had been learnt on the project, the fabricator said:

“The importance of physical models – that was definitely a bonus.” (Fabricator)
These physical models became a point of reference for conversations about how things fitted together and worked. The engineer said that:

“it’s fairly difficult to see very much at a time on the screen, your perception of the complex shape is…is quite limited, you have to make the thing move around and then you can’t quite remember what was on the other side, and it’s all a jumble because all the …and you see 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 physical models and vice versa with 2 model-builders and one digital modeller working as part of the team.

There are also other, perhaps less obvious benefits to the physical models. They did have value in terms of making the work visible to client managers:

“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)

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. Though the roof sub-project was remembered as an exemplar in the use of the Single Model Environment for co-ordination with other sub-projects, modelling played a key role in enabling communication with fabricators and temporary works designers. Thus, while the roof sub-project was a leading example of the use of digital models, there were used in conjunction with (rather than in isolation from) a set of conversations around physical models. It was the physical 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.

**Conclusions**

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, cardboard, rulers and plasticine. Without these 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, hybrid ecologies were continually mobilised as practices were performed.

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.

By shifting the focus from the tools to the ecologies of practice, the work has important managerial implications for the stabilisation of new technologies and practices and the management of technology in large construction projects. Elsewhere, Whyte (2008) has argued that information technology needs to be seen as an ongoing strategic issue, rather than a tactical issue, on global projects. In this paper we highlight the need for management attention to changing practices on the project and the need to support hybrid practices.

Positioning practice as something outwith 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 material as well as human components, and on collaboratively shifting 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.

Project management, in setting the agenda for practice, needs to provide a clear vision for technological change but also to develop and pay attention to the mechanisms for that change. Sometimes this involves a recognition and support for clumsy or hybrid solutions, particularly where the complexities of the tasks are not well supported by commercial software systems or translations. Uncovering where systems work through ‘plugging’ and ‘patching’ is a significant challenge to project managers on
large projects, as the reputational benefits of success mean that every project and IT system is described as delivering significant benefits.

Given the significance of ongoing work to develop Building Information Models on both sides of the Atlantic, this work in progress paper provides 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. Attempts to switch media are not simple substitutions, but can severely disrupt, transform or dislocate the very activities which are central to performing design and construction work.

The research also provides some new directions for research, showing the utility of concepts of actor-networks and of delegation as analytic tools. The concept of ‘actor-networks’ maintain the focus of research and analysis on the material as well as the social, and on tracing the dynamic connectivities between entities, rather than positioning them as discrete and bounded. The concept of ‘delegation’ provides both a tool for interrogating how various artefacts 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. The concept of an ecology of practice is useful in this context for understanding how IT use is situated within wider cultural and institutionalised practices. Currently, work is on-going which continues our investigation of the increasing utilisation of BIM oriented technologies, from a practice-based perspective. The work encompasses cross-comparisons across a number of large construction projects within the UK, and between UK and US projects.

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