Building Information Modelling and Management in Infrastructure Programmes: A Scoping Study in Crossrail

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ABSTRACT

The UK Government's Construction Strategy has huge implications for public procurement. Of particular interest is its Building Information Modelling and Management (BIM) Agenda, which calls for radical changes in the management and delivery of technical information for public projects to address issues of cost, value and carbon. Empirically-grounded research in engineering project organisations theorise current modes of organising, processing and managing technical information as a 'digital infrastructure for delivery' that supports the physical infrastructure. This digital infrastructure consists of the standards, repositories and various types of technical information required for delivering a project; it provides a mechanism for coordination, accountability and control, as well as for knowledge sharing.

Based on ongoing research in Crossrail, an ambitious UK public infrastructure programme, this paper examines how a digital infrastructure has become central to its delivery. Crossrail and Bentley Systems, its technology partner, are responding to the latest Construction Strategy, by focusing on advanced processes and systems for BIM. This initial scoping study draws from existing programme data, hands-on usage of digital collaboration tools, interviews, meetings, discussions and overall immersive research in Crossrail's technical design and innovation. The findings articulate how integrated software forms a digital infrastructure for delivery, through the combination of three distinct repositories of technical information: documentation (and asset documentation), building models and geographical systems. In light of the policy ambitions to support sustainable infrastructure through better quality data in BIM, the configuration of this 'digital infrastructure for delivery' provides a new means of organising, processing and managing technical information for handover to owners and operators.

Keywords:

Information management, technical information, digital infrastructure, BIM, design, innovation

1. INTRODUCTION

The UK Government's *Plan for Growth*, published alongside the 2011 Budget, highlighted the critical importance of an efficient construction sector to the UK economy. Contributing approximately 7% of UK's GDP, or £110bn, per annum in expenditure, the construction sector is a major part of the UK economy (Cabinet Office, 2011, Treasury and BIS, 2011). The UK Government, which represent public clients, is the single biggest purchaser of construction projects, representing around 40% of the sector's project pipeline, ranging from small restoration schemes through to large-scale infrastructure programmes (Cabinet Office, 2011). Given this particular dependence to public procurement, guidelines and requirements released by part of the Government are of upmost importance to the sector.

Following the release of the *UK Construction Strategy* in May, 2011, which summarises the very latest conditions for public procurement (BuildingSMART, 2011, Cabinet Office, 2011), the interest of stakeholders to the construction sector has risen dramatically. There is a pressing need for them to plan, manage and deliver their strategic and business responses against a strict schedule, whilst trying to meet the governments challenging objectives for their sector. The Strategy emphasises the need to deliver sustainable projects, by demanding significant reductions in carbon emissions, water consumption and waste to landfill. Another objective is to reduce public procurement costs by 20% by the end of this parliament's term. The strategy envisions altered organisational cultures, from adversarial to collaborative ones, whilst strongly encouraging radical innovation and information reuse throughout a project's lifecycle instead of cost-effectiveness during the bidding phase (Cabinet Office, 2011, BIMWP, 2011).

This paper addresses the research question *'How has Crossrail's technical information department mobilised a 'digital infrastructure for delivery' in the context of the BIM agenda and its aims to reduce carbon?* The next section presents the background to this study, with a brief overview of the UK government's BIM agenda and the existing research on digital infrastructures for delivery, which articulates the associated repositories, standards and different kinds of software and models. Section 3 then describes the research setting and methods. Section 4 describes preliminary findings of the study, which show three different and overlapping repositories in use within Crossrail. These are: documentation and asset information; 3D modelling (CAD) information; and geographic information.

2. RESEARCH BACKGROUND

Included in this new construction strategy, is the strategic requirement for all publicly-funded projects to feature Building Information Management and Modelling, or BIM. This is a managed approach to the whole-life collection and exploitation of an asset's information in an electronically-supported format (Cabinet Office, 2011, BIMWP, 2011). The *BIM Working Party Strategy Paper* (BIMWP, 2011) sets out an agenda for delivering BIM. It requires the use of BIM to deliver and maintain projects as a means to attain significant savings in cost, time and carbon, whilst increasing the value delivered to owners. For BIM to have such a profound impact, these policy makers argue for its widespread diffusion across the supply chain. They further argue that this diffusion would essentially translate to moving away from traditional organisational practices, which are based on a fragmented industry. Instead, practices should focus on lifecycle management, close collaboration between stakeholders and open information sharing.

The delivery of building and infrastructure projects involves the use of many diverse digital objects. Whyte and Levitt (2011) argue that rapid change in digital technologies is shifting the practices of project delivery, away from those described in traditional project management developed in the 1950's and 60's. Civil engineering projects present a unique opportunity to examine how organising is achieved through the interaction of people with objects, at specific places and times (Whyte and Lobo, 2010). As Whyte and Lobo (2010) put it, "*rich empirically grounded analyses of particular types of organizing have greater validity than theoretical* *generalizations about 'organizing' in the abstract*" (p.557). Research has begun to examine how project interactions are becoming mediated through digital models (e.g. Erdogan et al., 2008, Fischer and Drogemuller, 2009, Dossick and Neff, 2010), as engineering work increasingly involves the "*digital integration of information in construction*" (Whyte, 2011: p. 159).

Various authors claim that such efforts invariably address the sustainability challenges that have been raised on a global scale. According to Toffler (1984), long-term attempts to capture all forms of integrated knowledge in an organised way is one of the most worthwhile intellectual efforts in history, due to the inherent value that this offers in sustaining and advancing human civilisation. Jernigan and Onuma (2008) note that deploying 'integrated practice', the strong coupling in the supply chain required by BIM, translates to $15.8 billion in annual savings. The American Institute of Architects make an assessment with similar implications; they argue that projects using BIM save 5 to 12% in costs (Jernigan and Onuma, 2008). Besides enhancing economic sustainability, cost savings can directly translate to less carbon emissions and, thus, environmental sustainability (Cabinet Office, 2011, BIMWP, 2011, Cleveland, 2008).

Whyte and Lobo (2010) draw on a broad literature on objects and infrastructures (e.g. Star and Griesemer, 1989, Edwards et al., 2007) to describe components of the digital infrastructure in their context. They examine how work is organised and negotiated, and how knowledge is shared across the wide range of boundaries, drawing on the case of a European public-private highway project's use of a project extranet. They argue that integrated software is used to achieve tight coupling across teams and disciplines, affecting how knowledge is negotiated, coordinated and shared between professions. Standardised forms are integral to the use of digital repositories, as work becomes more radically distributed. Additionally, new digitally-enabled working methods significantly reduce discretion. In overall, work becomes highly disciplined, flow of information within hierarchies and across heterarchies become systematised, whilst digital tools and methods become integral to the project's processes. This combination of close coupling of digital systems, highly structured modes of organisation, and formalisation of workflows, prompted the authors to reconsider the established theory of coordination in non-work environments. They describe a '*digital infrastructure for delivery*' (Whyte and Lobo, 2010), that represents an organised and electronically supported system, used to support a project's delivery.

2. SETTING AND METHODS

Crossrail is currently Europe's biggest infrastructure project. At a cost of 14.8 billion pounds, it involves upgrading existing and constructing new lines over a 118 km route that transverses through Greater London, from Berkshire in the west to Essex in the east. When in operation, Crossrail will increase London's transport capacity by 10%, bring an additional 1.5 million people within 45 minutes of Central London and radically cut journey times between London's business districts – Canary Wharf, the City and the West End – and UK's busiest airport, Heathrow. In the context of the UK's BIM Agenda, the technology partnership between Crossrail and Bentley Systems is mobilised to develop leading practice through the delivery of a 'BIM-enabled' public infrastructure programme. They have a special interest in how the BIM Agenda can drive change in engineering project organisations. Moreover, they are interested in the evolving strategy for handing vital information to facilities managers, and how they can affect it.

This research has been carried out between January and April of 2012. Following the purpose, context and structure of an industrial-based engineering doctorate (Godfrey, 2012), the researcher has become part of the programme organisation by joining the Technical Information Department. This department is the architect, maintainer and manager of the *integrated technical information systems*. The researcher has also become part of the information solutions delivery partner, Bentley Systems. The data was collected through a number of avenues: informal discussions with managers and employees within the Crossrail's Technical Information Department during the time collocated in their offices (to date approx. 30 days); access to internal company documents and other data from both organisations, through their intranets; two departmental meetings and eight semi-structured interviews with managers and other professionals working within this department (interviews ranged from 1-3hours, with detailed notes taken). During this time there was also access to Crossrail's technical information systems, not least the digital collaboration tools and repositories; and observation of activities.

4. FINDINGS

Technical information is a major challenge in Crossrail, given the programme's scale. Data is located in three separate but interconnected technical information systems, which are used to manage documentation and asset information, computer-aided design models and drawings, and geospatial information. As shown in Figure 1, by the end of the programme there are expected to be 2-3 million records in asset information; 1 million model and drawing records; and a quarter of a million records held in the GIS. These systems are interconnected, so that users can, for example, click on an area of a map to open up a 3D model of a facility; or click on a drawing to obtain related asset information; or even directly link to asset information from the web-map.

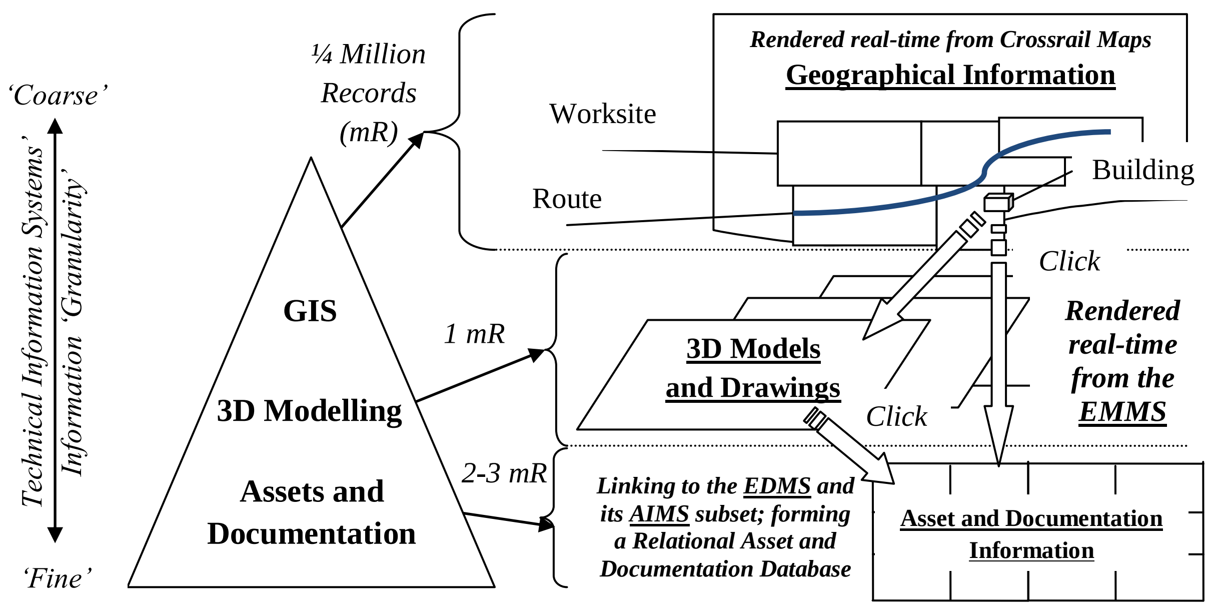

Figure 1: Crossrail's Integrated Technical Information Systems; supports real-time, interoperable and geo-spatially meaningful, graphical and non-graphical information

The technical information systems are maintained by a dedicated department that sits within the programme organisation. The scope of work for this department revolves around the concept of delivering maximum value to the railway owners; consequently, all activities are instructed to include an element of whole-life importance. Most employees within this department have worked on a range of other large-scale projects, notably the *Thames Link* and the *Jubilee Line Extension*. A few have been working for the Crossrail vision long before it was signed by the

Government – the train line has been advocated for since 1974 (Crossrail, 2012). These professionals have been sourced from a range of industries, such as IT, petrochemicals, asset and facilities management, technical information solutions, construction and railways. In the following sub-sections, the three different sub-systems that the technical information department currently manages are considered as separate digital infrastructures for delivery. These are documentation and asset information; modelling information; and geographic information.

4.1 Documentation and Asset Information

Documentation and asset information, which are treated as sets of *configuration items*, are considered in lifecycle terms rather than immediate delivery concerns. This consideration is particularly important in preparing for the handover phase, as Crossrail aims to release information in a vendor-independent structure, allowing operators to handle the information for their own purposes with ease and flexibility. The team builds on and contributes to the 'best practice' codified in industry standards. Crossrail is in ongoing discussions with the potential owners of the completed physical assets and systems and, therefore, programme information.

All documentation and asset information is being treated as *configuration items*, or individual bits of 'valuable' technical information, and are therefore subject to configuration management throughout the programme's lifecycle. Moreira (2010) describes configuration management as serving four core values in treating configuration items, each realised sequentially; these are: *identification*; *control*; *audit*; and *report* (also known as *status accounting*). These configuration items become subject to overall coordination of operations and system structure through particular enablers. These include *continuous training, defined management plans* and *business processes*, *internal and external specifications*, a *data dictionary* and the *perceived 'best practice'*. Besides continuous training, these enablers can be seen as standardised forms that articulate the essential blueprints of managing this particular category of technical information.

The enablers described above are mobilised to construct the *Electronic Document Management System*, or *EDMS*, which is used to manage the documentation repository. Most of the defined plans and business processes have been either coded in the *EDMS* or highly automated and facilitated through it. As such, they are usually automatically executed, without the user having much saying over this. The EDMS, which is available through Crossrail's extranet, is used to store, control, update, authorise, distribute and audit the millions of programme documents and records that are created during the pre-operational phases. The system operates against access levels and authorisation rights, whilst invariably requiring change control and approval for the data that it holds; consequently, auditing is highly facilitated. Moreover, the EDMS supports a document's metadata (including the links to repository locations), other non-document objects and the various relationships between the two sets. The object-based approach eases data mining, as multiple parameters can be used for sourcing related information by executing parametric searching. In line with the management plans, the documentation repository is populated with a long-term vision of handing over the required technical information to the future operators and maintainers in a fully-functional format, regardless of the technical system that they might use. The system, rigid as it is, allows for rapid exploration of documentation, in a relative efficient manner, based on an average usage profile. This practice builds upon a history of proven software solutions, providing a mechanism for good governance, quality control and quality assurance. In overall, by adopting configuration management principles, the EDMS has been formulated to provide consistent and compliant data across supply chain participants and at all times.

It is interesting to note how this EDMS has been especially re-configured to facilitate asset-specific data, resulting in a sub-management system that is superimposed upon a sub-repository; this system is termed *Asset Information Management System*, or *AIMS*. It takes central stage in coordinating, approving, storing and sourcing asset information, and mobilised by various teams to facilitate their discipline-specific work. The AIMS is structured around the *asset identification standard*, a highly standardised form which exactly specifies how asset information is broken-down, tagged, identified, referenced, synthesised and sourced. By following the standard's specific asset data structure, and abiding to the defined asset data dictionary, our research has shown that most, if not all, of the potential ambiguity in asset-related technical information, is mitigated. The system helps users to transfer asset requirements to contractors, as well as capture the configuration items that those contractors return. The champions of AIMS see it as a vehicle for information reliability and availability throughout the programme's lifecycle.

4.2 Modelling (CAD) Information

On large infrastructure projects, engineering work is organised through information models. In Crossrail, these are delivered by a truly diverse portfolio of contributors and throughout the pre-handover phases, involving both design and construction. The communication and consistency required have given rise to the need for a technical information system to handle this particular category of programme information, namely the *3D modelling system*. This system is the sum of a number of elements: the *modelling (CAD) repository*; the internal *Electronic Modelling Management System*, or *EMMS*, that is used to organise modelling-related work and which is superimposed upon the repository; the designers, contractors, operators and system maintainers that produce, handle, authorise or view modelling-related work; the various server-based and desktop-based modelling applications used to produce models; and the information exchanges that accrue due to the negotiations between all these elements. It requires constant maintenance and overview, as millions of digital objects will flow through it during the programme's lifecycle.

A '*building information model*' is a data-rich, object-oriented, intelligent and parametric digital representation of an asset. It is routinely used to extract and analyse a range of information, most significantly views. In turn, these can inform design, construction or maintenance decisions, given that they are properly used (Reinhardt and AGC, 2008). A model will usually contain all the information related to an asset, including physical and functional characteristics, as well as whole-life information, in an array of "smart objects" (Azhar et al., 2007). It can be used to encapsulate the geometry, spatial relationships, geographic information, quantities and properties of building elements, cost estimates, material inventories and project schedule. Consequently, the entire asset lifecycle can, theoretically, be summarised by a building model (Fleming and Sorenson, 2004, Bazjanac, 2004). Within Crossrail the final model takes the form of an '*asset model*'. This is the result of combining the 3D model with its related asset information, each sourced from two distinct repositories. The user of an asset model is essentially taking advantage of the integration between the two systems, thus experiencing their automatic interoperability and interdependence to carry out any technical activities that require such relational digital objects.

The ability of a small number of people to handle from 40 to 600 daily modelling-related servicing requests directly relates to such electronically-supported processes, as well as to the actual inter-organisational modelling structure observed. In overall, these can be understood as *standardised servicing structures*. An example of how these structures are mobilised to organise and ease the overall system can be identified by studying the servicing of *modelling (CAD)* *queries*. Following the defined structure, contractors are essentially required to manage, respond, and therefore be competent in, queries that originate within their own organisations. Where those queries cannot be attended by the dedicated modelling professional (*CAD system representative*) within the external organisation, they are forwarded to an expert within Crossrail which, taking advantage of a range of resources, responds to the dedicated external representative. In this way, data flows to and from Crossrail are not only highly structured and auditable, but also greatly reduce in quantity – compared to a non-structured servicing mode. Users become participants in a set of pre-defined processes; any negotiations will not normally debate the workflow, but rather the actual digital objects that flow within the defined and strict structure.

The programme participants are obliged to store all modelling deliverables, through the available extranet, within the modelling repository. Additionally, the modelling deliverables need to be streamlined through the EDMS and pass all of the approval stages, in the same manner in which other documents are signed-off. The exact same rules are applied to the modelling deliverables. Clicking the hyperlink, however, opens up the EMMS, which is superimposed upon the modelling repository. Most tier 1 contractors use the same vendor-specific software applications, despite them not being mandatory. The only condition for designers and contractors is to save their models in a specific and agreed format, thus allowing for interoperability. Quite recently, the programme organisation has been allowed to manage the licenses of the vendor-specific EMMS. The nesting of objects is particularly observable in dealing with modelling information.

4.3 Geographical Information

Crossrail hosts a comprehensive *Geographical Information Systems* (*GIS*) facility, which is available to most programme stakeholders. Across all departments, areas and phases, people working for this programme inevitably require some sort of geospatially-related data. The system is designed and used to capture, store, manipulate, analyse, manage and distribute all types of geographically referenced data. Crossrail's GIS has become possible by merging cartographic and statistical analysis with enhanced database technologies. The team responsible for this area manages and distributes the wide range of geographical data across the complete Crossrail supply chain. It also performs various technical services, ensures that the mapping platform is maintained, and provides expert training upon request. Industry standards, perceived 'best practice' and the internal management plans play a crucial role in guiding the team's operations.

Crossrail Maps provides a medium for answering the wide range of geographically-related requests made by both internal and external participants. This web-based mapping interface enables rapid exploration of programme data through geographical objects. It is provided securely over the internet, as part of Crossrail's extranet. In contradiction with the EDMS, it does not support change control, since only the most recent approved data is available. Users are able to navigate around the complete Crossrail estate through a simple, 'non-disruptive' window, which streams real-time data from the geospatial, modelling and asset and documentation repositories. Crossrail maps is a user-intuitive mapping service, based on a user-friendly interface that supports dynamic exploration of geographically-referenced digital objects. The platform allows for powerful functions, through the provision of mapping and measuring tools, the ability to dynamically navigate across the complete estate, as well as the possibility to isolate particular layers of information. These functions ease other, non-graphical workflows that might require the usage of this map, potentially offering significant cost and time savings.

The provision of Crossrail maps requires that data is streamlined to it, that the system is adequately supported, and that the information is consistent and accurate. This requirement gives rise to a standardised form that captures the flow of geographical data, from source to mapping user. The sources include organisations and databanks such as utility companies, the UK Ordnance Survey, Olympic Routes, National Rail and other third parties. They provide bundles of geospatial datasets, constructed by five layers. Once collected, the data is aligned and approved against Crossrail's requirements. Subsequently, they are stored in dedicated geospatial servers. These are linked to the programme's technical repositories, as they are attached to other objects, thus providing geographical meaning to them. The repositories and servers can be accessed in real-time and seamlessly as part of Crossrail's extranet, through the internet.

Crossrail maps is enabled through the interactions between three different repositories. Had the mapping interface not included asset, documentation and modelling information, it could very well operate by streaming only from the geographical repository. Yet it is the integration of data from all these technical information repositories, through standard data workflows, that enhances the technical information systems. As seen in figure 1, the super-platform improves the technical information that it covers, be it graphical or non-graphical, by making it interoperable and geo-spatially meaningful. The *integrated technical information systems* attempts to provide true seamless transition between the various levels of granularity that characterise the programme's technical information. A remotely-located user can navigate from the overall programme map right down to a specific asset's information, either directly or via a 3D model. Compared to a traditional approach, which would translate to exploring the technical information by opening at least different applications and not being able to see the links between its levels, this super-platform provides a much quicker and smarter vehicle for information mining.

5 Concluding Remarks and Next Steps

The scoping study in Crossrail shows the extent and complexity of digital infrastructures for delivery of large infrastructure programmes. This is important because of the government BIM agenda, and its use as a mechanism to reduce carbon. In Crossrail there are three kinds of data, documentation and asset information, modelling, and geographic information, which are organized in separate but interlinked systems, where the geographic information system becomes used as a window onto the wider data of the programme. Hence the study extends what has been written about digital infrastructure, showing how these different repositories interact with, and build upon, each other, as the systems increasingly becomes co-dependent and nested. This close coupling and integration advances the range of technical-specific programme knowledge.

The integration of all the different kinds of data under a common extranet offers a portal for visualising complex problems. The almost seamless transition between repositories, data, disciplines and information in a visually enhanced setting, as seen in Crossrail, can serve a multitude of specialised tasks. Expert teams can renegotiate and re-write their own workflows, to include the use of the sophisticated functions offered by this integration. In this way, programme knowledge is mobilised in a new context – enhanced digital collaboration coupled with visual intuitiveness. Of course, documenting how the wide array of programme teams are utilising, and will continue to do so in the future, is a monumental task. Nonetheless, observing how teams are all the more requesting specialised, geographically-referenced content, such as those offered through Crossrail Maps, can only indicate towards their inherent value. In turn, these can be used to either enhance or ease the tasks required by these teams, under the overall programme's scope.

This research has some important limitations that could inform future directions. It does not study how construction, an important variable in determining overall costs and environmental impacts, is being mobilised under these new settings. We are also unaware of digital collaboration practices by part of contractors, or if these are indeed being used to inform plans and real-time decisions. The existing research, as documented in the previous pages, is limited within the core programme organisation. It would be interesting to extend our investigation to tier 1 contractors and even Crossrail sites. Additionally, the research lacks in exactly determining how the integration of repositories leads to mistakes being identified and avoided, and how the ability to visualise information is extending programme knowledge. Moreover, there are 'unknown unknowns' arising as a result of utilising a platform of visually-enhanced and geographically-referenced data; we are still unable to determine how expert teams use the functions offered to address concerns for sustainability in engineering practices and programme delivery.

How is sustainable infrastructure delivered through this digital infrastructure for delivery? One claim made in the UK's construction strategy is that delivering better information will help manage and measure performance through the life-cycle. There is a need for further research to develop appropriate metrics to ensure that information is being mobilised to this end. Next steps may include the development and codification of a robust and repeatable method for assessing the impact of data and information management, in financial, operational and environmental terms. Moreover, the claim that BIM results in sustainable projects should be tested. A possible approach to this could be to evaluate the monetary returns or savings by capturing data on the mistakes that get identified and avoided before construction. In doing so, developing a method for estimating the embedded carbon of such mistakes would prove useful. Best practices and lessons learnt from Crossrail, as well as comparing these with the implications from other large-scale infrastructure projects, have the potential to strongly support the above research directions.

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