Digital delivery of infrastructure projects; impact and management issues within a project-based engineering firm

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Abstract:

The use of digital technologies for engineering design is receiving rising interest by both academia and the architecture-engineering-construction (AEC) industry. In the UK the government's new construction strategy to achieve fully collaborative BIM projects by 2016 is a further catalyst. Research in the field is too often focused on digital technologies and associated digital practices as implemented in major projects. Longitudinal case-study research is used to understand the impact and management issues associated with digital delivery of projects within a large international engineering firm. The data shows that technologies to manipulate and manage engineering data, communication and information infrastructure, and digital data standards are emerging as digital infrastructure for the firm's engineering design work; this digital infrastructure is in-complete and it takes the form of foundation systems to enable standardized ways of working across the different parts of the project-based firm, while leaving room for customization to meet the specific needs of different market sectors, projects and clients. The findings of this research improve our understanding about the digital infrastructure for project delivery and the tension between standardization and flexibility within project-based environments, and hence contribute to research on technology and organizations.

Keywords:

Digital technology, infrastructure, management, project delivery

1. Introduction and theoretical framework

Digital technologies in the form of shared databases and repositories, software applications, digital tools and systems, and digital data standards are becoming integral component for engineering project delivery. The emergence of integrated project delivery (IPD) and building information modeling (BIM) concepts emphasize the role of these pervasive technologies as combinatorial innovation as well as digital platform for the firms who are engaged on design and engineering of infrastructure projects (Youngjin, Boland Jr et al. 2012) rather than being treated as separate technologies, and this has several implications for research and practice. In the UK the government's new construction strategy to achieve fully collaborative BIM projects by 2016 is a further catalyst (Strategy 2011), and hence firms are investing on the development of these digital platforms and capabilities in order to meet the goals of the government initiative and remain sustainable in a competitive market.

Growing body of research is articulating the impact of using digital technologies for design and engineering of buildings and infrastructure, (Dodgson, Gann et al. 2007) describe how digital technologies improve engineering design by providing learn-

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before-doing opportunities for engineers, (Whyte and Lobo 2010) demonstrate how the digital infrastructure for delivery enhance design coordination for project work, and (Gal, Lyytinen et al. 2008) show how digital technologies facilitate cross-organizational communication. Moreover, scholars observing practices during the introduction of digital technologies for major projects has found that these technologies induce innovation across multiple professional communities (Boland, Lyytinen et al. 2007), and disrupt the ecologies of practices resulting in new hybrid practices that combine the traditional physical with the emerging digital practices (Harty and Whyte 2010). This growing body of research is useful for the understanding of the implications of the introduction of digital technologies for engineering design project work; there is an urging need to take the research on digital technologies beyond the project level to consider the implications, management and practices associated with these pervasive technologies within the firm on its totality.

Firms within the architecture-engineering-construction (AEC) industry follow the project-based form of organizing, which found most suitable to manage their complex products and systems (Hobday 2000). In a project-based firm profits and values are generated by professionals working in projects who are usually based off-site and working in teams with other firms, they operate at the boundaries of the firm and have weak ties with the main stream organizational structure and control mechanisms (Gann and Salter 2000; Scarbrough, Swan et al. 2004). This form of organizing has important implications on the management of digital technologies.

Previous studies found that project-based firms within various sectors have the potential to support innovation through different ways. (Keegan and Turner 2002) found that professionals working on multiple projects simultaneously and over time plays the role of boundary spanners and broker new knowledge and ideas, also free and intense communication and information flows through formal and informal ways blur the boundaries between functional groups within the firm and improve integration, moreover, decision making within this form of organizing is based on expertise rather than positional authority. However, and despite these benefits, construction project-based firms continue to struggle to manage innovations, (Gann and Salter 2000) found that construction firms *fail to build links between operations at the project level, portfolios of projects, and central routine activities*.

The tension between the project and the firm levels of analysis when considering innovation adoption and management has been highlighted in previous research as one of the main implications of the project-based form of organizing. (Gann and Salter 2000) emphasize the importance of understanding the differences and intersections between the more routinized business process at the firm level and the temporary and unique project processes when considering innovations in construction, while (Harty 2008) promote the concept of bondedness to account for the messy and complex dynamics of construction work. The consideration of this tension between firm-level and project-level processes and the differences between them is important when studying the introduction of technology for project work within large engineering firms who are engaged on the delivery of infrastructure projects.

The management of technology in project-based firms made difficult by the dynamic and evolving nature of the technology and associated working practices at one hand, and the idiosyncratic and complex nature of the project-based form of organization in the other hand. The aim of this research is to address this challenge through describing the digital technologies used for project delivery and articulating the associated management practices, drawing from a longitudinal case study within an engineering project-based firm.

The paper is organized as follows: section 2 describes the research design and approach including overview of the case study firm and the data collection and analysis methods. Section 3 presents the findings of the case evidence through the description of the different elements of the digital delivery of infrastructure projects within the firm and its associated management challenges. Section 4 discusses these findings in relation to the literatures on construction project-based firms and digital infrastructure, and concludes with the implications of this research on practice and theory.

2. Research methods

The design and development of this research follows an engaged scholarship approach, this is a participative form of inquiry where researchers involve others (practitioners and other stakeholders) and leverage their different perspectives to learn about a problem domain (Van de Ven 2007). The research process iterates between the four elements of the engaged scholarship model (problem formulation, research design, theory building and problem solving) involving the case study firm as research partner rather than research object. Furthermore, this case study adopts iterative and multiple data collection instruments in an inductive manner to enable theory building from empirical data (Eisenhardt 1989).

The case study firm

The case study firm is an international engineering firm that specializes on planning, design and management of buildings and infrastructure. The firm currently consists of:

a- 3 global practice areas (development, natural resources and transportation), with several market sectors within each of these practice areas, for example transportation include: rail, airports, highways, tunnels and underground spaces, and bridges. Various skill groups provide the technical resources to these market sectors and engage on project delivery activities, and

b- Central corporate and support services: group business development, human resources, security, finance, secretariat, health and safety, IT and corporate communications, amongst others. These corporate services provide support for the practice areas across the different parts of the firm.

As such the organizational structure of the firm follows a project-based form of organizing.

Within this loosely coupled organizational structure technology was embraced within each practice area and market sector differently, some groups were more advanced on their use of technology than others, depending on various factors such as clients' requirements, complexity of work, available skills and knowledge and awareness of technology and its benefits. Some groups were heavily relying on simple tools and applications such as excel sheets for modelling and simulation of information, while others, such as the transportation business group for example were using sophisticated software packages for the production of engineering designs as well as for data management and collaboration, this has been attributed to the strict compliance and systems required by the clients of this market sector.

In general the firms' projects are delivered through two types of professional work:

1. Business development and marketing (or bidding): this work is performed by groups of professionals who are responsible for identifying and working on bids to win projects at regional level. To achieve this they need to work towards meeting clients' and local needs norms and laws. They need to weight profit and loss with resources and investments. Most of the engineering design work at this level is conceptual with the need to demonstrate technological capabilities that will be used later after winning the project and this normally include examples from other projects and available resources within the wider firm.
2. Project delivery: and this comes following the successful winning of bids, and where the actual activities of project delivery takes place, engineers and technicians interact with other stakeholders outside the firm in engineering work that involve myriad of digital technologies that vary on its sophistication and capabilities to develop and produce design solutions. Productivity and quality of delivery are the main issues at this stage, the use and management of technology at the project level is vital to achieve these issues.

Moreover, to support the above project work, there are centralized technical services to maintain the firm's information infrastructure that enable communication, coordination and information management, as well as other consulting services provided by specialized groups such as finance modeling.

Data collection and analysis

This research project started on November 2009, the first data collection phase was started with a pilot study on June 2010, followed by two phases of data collection over the summers of 2011 and 2012, and the research is still on going. The evidence presented in this paper is collected through: 28 semi structured interviews with engineers, CAD professionals, technology managers, and directors, notes from attendance of 18 internal meetings which also include meetings for research design and report on progress, study of internal useful documents within the firm's intranet system, and numerous informal interaction through the days spent at the firm's offices. Also various materials about the firm and relevant websites were looked at during the course of the research.

The data analyzed qualitatively to understand the technology used for project delivery, and to seek interpretations for the use and management of technology from the evidence (Creswell 2003). Theoretical conceptualization overlapped with data analysis and literature reading. The interviews were transcribed verbatim, the content of the interviews assigned to codes using the qualitative data analysis software package Nvivo, the data analysis started with high level codes around: the digital technology, means by which knowledge about the digital technology transfer, and issues related to the firm as the social system within which technology and its practices spread. Then after, codes were refined, merged, and grouped while going back and forth through the data and themes emerged through the looking for similarities and differences within interviewees' statements.

The data analysis was more descriptive and exploratory to enable sense making of the technology, its management, and the context within which its practices are spread. 40 pages of field notes used to compare and contrast findings with the data from the interviews. Any clarification or new thoughts were added through the process of writing the findings. Facts and information found on related websites were used for general positioning and to make sense of the firm's markets and projects.

3. Digital technologies for engineering project delivery

Wide range of technologies is found to be used for project delivery within this large and international firm. The evidence from the case study has showed that digital delivery of infrastructure projects within this firm rely on three types of technologies: technology to manipulate and create engineering design data, technology to manage and enable collaboration when work with digital engineering data, hard infrastructure and communication technology, and digital data standards. The different stakeholders of the project engage on professional and collaborative work to deliver engineering design digital data that can be used later for construction and running of infrastructure projects.

These technologies have been described by technology managers within the firm as foundation systems for digital and global delivery of infrastructure projects; this is discussed by the technology management director interviewed in 2010:

"and therefore, we're very much into putting in what we term the foundation systems that support elevated working methodologies and also will support BIM in terms of electronic document management systems, standard file naming, the ability to search and retrieve data"

These foundation systems are proposed to provide standardized ways of working that can be tailored, customized and upgraded to meet the specific needs of the various market sectors, projects and clients. These are illustrated on figure 1, and described on the following sections.

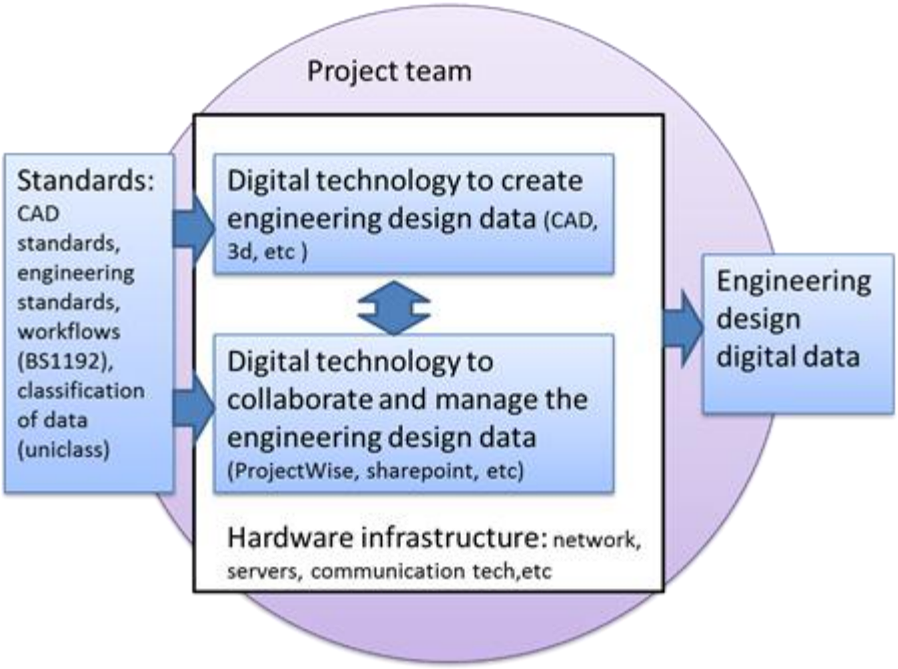

Figure 2: Digital technologies used for infrastructure projects

Technology used for the creation of engineering design data

Engineers and CAD technicians use wide range of technologies to manipulate engineering design data, in addition to the basic drafting applications such as CAD packages provided by well-established construction technology providers, engineers use discipline specific applications for more specialized engineering work, these tools are called bolt-on tools. The use of specific tools or applications depends on the complexity and the stage of the design as well as the knowledge of the engineer this is has been explained by a graduate engineer interviewed on 2011 as follows:

"we have got sort of three levels of software you could use, you could just use an Excell spreadsheet and some basic equations and that would be for your very simple approach. You could use something like X Disp which is….uses those same simple equations but because it's got a nice user interface you can model on much more complicated situations or you can use Finite Element, Problem Finite Element Analysis such as Plaxis which I don't know how to use but other people do, which models everything in much more detail and is theoretically much more accurate."

The engineering work itself in the form of mathematical calculations or the physics of structural materials hasn't changed overtime this why the old or simple technology is still in use beside the new and more sophisticated technology, and factors like the engineer's experience or the value of the job decide on which technology to use.

The use of advanced engineering software applications and tools improved the outcomes of the engineering design process by the manipulation of available data to provide more accurate and closer to reality information as discussed by the same graduate engineer in 2011;

"it can provide reassurance that what you think is going to happen is likely to happen. That you have got some sort of mathematical and theoretical basis for what's essentially sort of best engineering judgement. So if you expect something to

move by 10 millimetres then you use a piece of software that tells you it is going to move by 11 millimetres, you know that you are in the right sort of area and that 10 is about right. So it's sort of…rather than giving you the actual answer it supports your theory as it were."

This knowing before doing has improved engineering design by providing the needed reassurance to overcome some design uncertainties; it also improved engineering design by eliminating problems at later stages of the design and construction

This kind of digital innovation is widely used within the engineering work and can be seen as institutionalisated within the firm; however, standards to regulate and ensure the quality of it are developing such as the firm's CAD standards, engineering standards that each engineering discipline needs to adhere to, as well as client-specific standards that are important to comply with.

Technology used to manage and enable collaboration in the creation of engineering design data

The project work of this firm is like other engineering design firm involves multi professionals from different locations working on one project or multiple projects at one time. Collaboration is an important aspect of the project delivery, digital technologies are used to enhance this collaboration, and yet, the use of technology poses challenges for the management of digital data in collaborative environments following a consistent and timely manner. One example of challenges face engineers working on teams is confusion with drawing versions as described by water engineer interviewed in 2010:

"So they might work on the drawings of Revision C2, they rename it C3 they come back to it a week later do some changes put it at C4 and you issue it as C4. But you might not have issued C2 or C3. It's just that they've, yes? So again that's not so bad but people just query why they haven't got revision C2 and C3 and straight to C4. Which is the confidence you need. Yes we tend to put clouds around revisions but when you go from a C2 to a C3 you'd delete the clouds for C2 and put new ones on for C3 so you might miss those."

Technology to manage digital engineering data helps engineers to overcome collaboration challenges through the management of digital data produced by the technology described in the previous section, In addition to improved collaboration with engineering digital data, this kind of technology also provides assurance to clients that their project data has been managed following clear quality measures than can be proved:

"It (projectwise) provides a lot more assurance to clients like London Underground, that you have got a process that demonstrates people have checked it, and you can prove that the project manager actually opened the document and looked at it, which they like."

An example of this is the management of CAD data through the use of software applications such as Projectwise which is emerging as the main tool for digital data management within the firm, it does not just provide repository for the project data, but it applies discipline to the way that data is created reviewed and shared, it also has a work flow engine built into it which follows BS1192 standard:

“That’s [projectwise] really our bread and butter collaboration tool for projects worldwide. Now this is going through a major development at the moment. Previously it has been relatively small scale in terms of the number of projects and the participation in those projects by the project teams being very UK centric and we are just beginning to see that taken up internationally”

As quoted above by systems manager interviewed in 2011, this technology is emerging within the firm, it is just started to be realized as important, user intervention and training are the main issues regarding the management of this technology. Technology managers need to engage on more activities to promote this technology and explain it benefits and how can it helps improve project delivery. If data standards and workflows embedded within this kind of technology collaboration will be achieved successfully.

Hard infrastructure and communication technology

Technology always thought about as composed of soft part; that the software application, and hard part which is the hardware. To enable communication, information management and digital delivery the firm relies on hard infrastructure that is comprised of communication technologies such as telephony and video conferencing, as well as hard infrastructure in the form of: data centers, networks, servers, desktop and service desk management. Backup software and virus protection are also important.

This leading engineering firm is one of the early adopters of the OCS divergent technology which enables more collaboration through the means of shared text, voice and video facilities, this described by an IT support analyst interviewed in 2011:

“OCS is a big one. Unified communication. That’s made a big difference. So, next door you would have your email and you would have your land line and your mobile, now you know with unified communication all three are linked to each other so you use software on the desktop. You type in somebody’s name and you can call them. You know it’s so much easier. I think that has made a big difference”.

This type of technology is witnessing radical changes through the advancement of web technologies and the internet, cloud computing has the potential to override current hardware infrastructure by providing virtual versions of it which leads to cheaper and more accessible services.

Digital data standard

In this digitally-enabled collaborative engineering work digital data needs to be handled in standardized and consistent way. CAD standards provide consistent way of producing CAD drawings, while discipline-specific engineering data need to comply with specific standards to ensure quality of the engineering design solution. With the emergence of digital data classification and specification of this digital data is also important. Standards such as BS1192: 2007 are specifically developed to regulate and manage the collaborative production of architectural, engineering and construction information, and hence it is important to regulate the digital data of this collaborative work

4. Discussion and concluding remarks

The findings from this research have a number of implications. First, they describe the components of the digital infrastructure for the firm to support project delivery, these include technologies to manipulate and manage collaboration around digital engineering data, digital data standards and hard and communication infrastructure. This digital infrastructure is incomplete, it provides foundation systems that stand standardized ways of working across the firm which then can be configured and updated with the requirements of specific market sectors, projects and clients. The digital infrastructure evolves over time through the continuous engagement of the firm in projects and project work, this finding agree with Whyte and Lobo (2010) who claim that such infrastructure is not completed in one go, but rather is developed through work in particular projects and through drawing connections across projects, however, the evidence presented here demonstrate the digital infrastructure for the firm as a whole.

Second, the findings of this research account for the tension found in project-based firms between the routine centralized business process, and the more unique and autonomous project processes (Gann and Salter 2000) by providing the firm with in-complete digital infrastructure that offer standardization and customization at the same time, the provision of foundation systems for digital delivery of projects provide standardized forms of digital project work across the firm, and as discussed above, this standardized digital infrastructure stand as foundation that can be upgraded, reconfigured and customized to address specific needs of the different market sectors, projects and clients.

The contribution of the research presented in this paper is to describe digital technologies used for project delivery, and to articulate its impact and associated management practices. As described above, three types of technology were identified by the empirical data: technology to manipulate and create engineering design data, technology to manage and enable collaboration when work with digital engineering data, hard infrastructure and communication technology, as well as digital data standards, these digital technologies are described as foundation systems that can be used across the project-based firm as a standard ways of working which can be upgraded and customized into market sector-specific digital infrastructure. This is important because it improve the understanding about the emerging digital infrastructure for project delivery. It extends existing understanding of the impact of the use of digital technologies in major projects to account for the implications and management of these technologies within an AEC project-based firm. It is of practical importance for engineering firms facing new ways of digital work because it articulates digital infrastructure for global delivery of infrastructure projects across the different parts of the firm.

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