Chapter 17[1]

INFRASTRUCTURE MEGAPROJECTS AS ENABLERS OF DIGITAL INNOVATION TRANSITIONS

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17.1 Introduction

Innovation refers to the development of a new product, service or process (Abernathy and Clark, 1985). Novelty and innovations are often observed in projects (Shenhar and Dvir, 2007). Innovations are highly context-dependent and rely on good projects (Shenhar and Dvir, 2007). Infrastructure megaprojects have a particularly close relationship with innovation *(Davies et al.*, 2009). This relation between innovation and its context, such as infrastructure megaprojects. is important for understanding innovation. Digital innovation is differentiated from other innovations as it is highly pervasive and systemic (Egyedi and Sherif, 2008). This chapter increases our understanding of digital innovation and its relation to institutional contexts, especially infrastructure megaprojects. Focusing on the relation between digital innovation and infrastructure megaprojects, such as London Heathrow and Crossrail (Davies *et al.*, 2009; Dodgson *et al.*, 2015), shows how these infrastructure megaprojects influenced institutions through standardisation to promote digital innovation.

The chapter draws upon the work by Davies *et al.* (2009) on how innovation and particularly digital innovation was used in megaprojects to achieve government-led standardisation outcomes. Megaprojects, due to their embeddedness (Blomquist and Packendorff, 1998), longevity and pervasiveness, offer a rich research setting to understand the interplay of institutions and agency. Any organisational unit, actor or agent shapes and is shaped by its environment or structure, also called embeddedness (Giddens, 1984). As projects are inseparable and essentially embedded into their issue, organisational and institutional contexts are quintessential for understanding and managing projects (Blomquist and Packendorff, 1998). Not only should projects' relational context be continuously managed, but their wider institutional environment also merits attention (Blomquist and Packendorff, 1998). Söderlund (2004) acknowledges that whereas project management discipline has its "intellectual roots" in process planning and a Taylorist approach to workflows, it has developed into a hybrid field that incorporates many strands of social science.

The relation between projects and innovation is well-documented in scholarship. Davies (2014) recognised two contrasting models of project-based innovation; one optimal, emphasising planning and formal processes and another, adaptive, governed by uncertainty and adaptation. In the adaptive model, individual agency, informal processes, tacit knowledge and context shapes projects through innovation. This chapter focuses on the adaptive model of innovation (Davies, 2014) as is suitable for studying the highly dynamic context of digital innovations. Using the concept of multi-level perspective (MLP) by Geels (2004) as an analytical lens, this chapter investigates the relation between infrastructure megaprojects and their institutional setting to understand how the UK construction sector is currently undergoing a transition from traditional to digital. The authors begin by appraising relevant literature on innovation, highlighting studies relating to infrastructure megaprojects. Then, a longitudinal data relating to digital innovations in UK infrastructure megaprojects and its analysis is presented. Finally, a summary of the case and managerial implications of the study are discussed.

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[1] From the book:
Ochieng, Edward, Tarila Zuofa, and Sulafa Badi, eds. *Routledge Handbook of Planning and Management of Global Strategic Infrastructure Projects*. Routledge, 2020.

17.1.1 Chapter aim and objectives

This chapter aims to perform the following:

- Introduce the concept of digital innovation and differentiate it from innovation;
- Explain how actors, institutions and infrastructure megaprojects influence digital innovation;
- Present how six infrastructure megaprojects in the UK supported digital innovation;
- Discuss the socio-technical system view of multi-level perspective (MLP);
- Describe ways that the public sector can influence digital innovation; and
- Illustrate key transitions in digital innovation in the UK construction sector.

17.1.2 Learning outcomes

The following learning outcomes have been identified for this chapter. Readers will be able to:

- Articulate the concept of digital innovation and be able to differentiate it from innovation;
- Analyse how actors, institutions and infrastructure megaprojects influence digital innovation;
- Evaluate how infrastructure megaprojects support digital innovation;
- Appreciate the socio-technical system view of MLP;
- Synthesise ways that the public sector can influence digital innovation; and
- Identify key transitions in digital innovation in the UK construction sector.

17.2 Theoretical background and knowledge gap

17.2.1 Innovation footprint of infrastructure megaprojects

Megaprojects are projects with investment of more than US $1 billion and are often found in infrastructure projects in transport, energy, and communications (Sanderson, 2012). Because megaprojects are large complex systems, systems integration has been proposed as a strategy to deal with complexity (Davies and Mackenzie, 2014; Davies *et al.*, 2014). Systems integration is also applied to facilitate innovation and improve megaproject performance (Davies *et al.*, 2009). Geels (2004) defines socio-technical systems (STS) in an abstract sense as the linkages among elements necessary to fulfil societal functions, such as transport, communication, nutrition, etc. Technology is a crucial element for fulfilling those functions and STS encompass the production, diffusion and use of technology, as technology is a sub-function for these major societal functions. Hence, STS consist of artefacts, knowledge, capital, labour, cultural meaning and so forth. To this end, megaprojects are socio-technical niches.

There is a strong relation between projects and innovation (Shenhar and Dvir, 2007) and especially infrastructure megaprojects, due to their longevity, multi-stakeholder engagement and pervasiveness in the institutional setting, are ideal organisational vessels to study innovation. Megaprojects and project-based organisations (Hobday, 2000) are closely linked as the latter are vehicles to deliver the former. Megaprojects are projects of massive, significant scale with long delivery phases that span years or even decades. In particular infrastructure megaprojects carry societal value due to their social functions. Apart from societal impact, megaprojects are usually notorious for poor delivery performance (Flyvbjerg, 2014). Among others, scholars usually emphasise their front-end management, the promoter's role (Gil and Pinto, 2016), their embeddedness into their context (Blomquist and Packendorff, 1998) and involvement of numerous external stakeholders. Megaprojects have a bespoke nature and high uncertainty.

Megaprojects are undoubtedly long-standing, behave as organisations and depart from the traditional notion of project temporality and uniqueness. Sydow *et al.* (2004) explained that despite the fact that organisations usually outlive their projects, the two have similar learning mechanisms. Whereas there is a general notion of temporality of megaprojects, *Brookes et al.* (2017) questioned the "dichotomy of durability between a longer lasting organisational milieu and an ephemeral project." Second, project typologies, such as those of transportation and oil and gas sectors, allow for a degree of repetition. Repetitiveness may account for less uncertainty and more predictability, even in unique, long-standing, and complex projects (Davies and Brady, 2000), due to the "economics of repetition." Therefore, despite being unique, infrastructure megaprojects have mechanisms for transferring knowledge across other projects and their context and supporting innovation (Davies *et al.*, 2009; Davies *et al.*, 2014; Davies and Mackenzie, 2014) in the sector.

17.2.2 Contextual transitions from innovation to digital innovation

Historical advancements in hardware and software gave new IT capabilities to infrastructure megaprojects (Whyte and Levitt, 2011). These megaprojects have a bilateral influencing relation with their context. Giddens' structuration theory (1984) suggests that social systems, such as projects and megaprojects, shape and are shaped by their environment by having a mutually constitutive relationship and being embedded in a wider context. This insight calls for understanding megaprojects and innovations as not only being capable of shaping their environment, but also being shaped by it, according to the duality of structure and agency in structuration (Giddens, 1984). Innovation depends a lot on its context. For Rogers *et al.* (2005), contextual heterogeneity is central to his diffusion of innovations theory, and acknowledging the influence of heterogeneous institutional contexts offers a grounded grasp of innovation.

However, digital innovation is inherently different than innovation, as it is unbounded – that is, it relates to more than one discipline or multiple agents; it is related to distributed agency and the innovation processes and outcomes are interrelated (Nambisan *et al.*, 2017). Digital innovation is different from innovation as digital technologies are used during the innovation process (Nambisan *et al.*, 2017). The transition from innovation to digital innovation creates new challenges and transformations in individuals, organisations and more widely, in society (Nambisan *et al.*, 2017). Digital innovation as a socio-technical phenomenon challenges key assumptions of innovation management. Hence, digital innovation due to its particular features is better understood within its context and at the same time, relates to many different institutions and actors outside the traditional supply and demand chain.

From a neo-institutional and STS view, Geels (2004) and Geels *et al.* (2017) provided a MLP for looking at innovation as STS where actors and institutions interact through different rules and induce transitions in the innovation landscape. In this macro-level view of innovation, Geels (2004) distinguished among (1) actors and social groups, (2) rules and institutions, and (3) technologies and STS that interact in a dynamic manner. These actors and social groups are embedded in the STS and use the rules of the institutions, for example, to introduce new technologies, make investment decisions about technology or develop new regulations and standards. These actors have different resources, such as money, knowledge, tools and opportunities to realise their decisions and influence social rules (Geels *et al.*, 2016). Through various interactions between actors and social groups with rules and institutions, various events can be mapped that eventually shape the transition of the innovation landscape. These transitions shift between the following pathways: "substitution," "transformation," which leads to "reconfiguration" and is possibly followed by "re-alignment and 'disruption"(Geels *et al.*, 2016).

Negotiating and setting rules and standards are part of the innovation process through a neo-institutional and STS view. Standards can be defined as consensus reached by various actors on how to do specific activities according to agreed-upon rules (Farrell and Saloner, 1992). Standardisation, that is, the development of standards, supports also the legitimisation of the technology and these standards (Narayanan and Chen, 2012). Among the various institutions involved, the government is recognised as one of the most important standardization actors (Gao *et al.*, 2014). This is because the government typically promotes technology development, implementation and diffusion by research and development, technology investment and forming state-led standard-setting consortia (Funk and Methe, 2001). The government is not only a regulative but also cognitive and normative institution for supporting standards and innovation (Gao *et al.*, 2014). Key actors in standardisation are firms that build capabilities (Xie *et al.*, 2016) and are organised in megaprojects (Davies and Brady, 2000).

17.2.3 Research setting of innovation in infrastructure megaprojects

Innovation has been traditionally considered "incremental" (evolutionary) by involving gradual minor changes and "radical" by engaging in completely new approaches (Abernathy and Clark, 1985; Burns and Stalker, 1961). In construction, which is largely project-based (Morris, 2004), innovation is considered to have a slow uptake and undergoes slow transitions. In the last decade, the construction industry has been transformed by "wakes" of innovation in project networks (Boland, Jr *et al.*, 2007). [AQ1]From digital three-dimensional (3D) representations of built assets until automated design and construction processes started using Building Information Modelling (BIM) – a three-dimensional data modelling approach – and various realities (Whyte *et al.*, 2000), the construction sector has witnessed changes in technologies, work practices and knowledge across multiple communities (Boland, Jr *et al.*, 2007). Presently, BIM is considered the most representative digital technology and information aggregator in construction globally. Following similar trends in other sectors, the advancement of construction IT has evolved within the context of the digital economy. Accordingly, various digital artefacts and functionalities alter the way construction megaprojects are designed and delivered (Whyte and Lobo, 2010). Lobo and Whyte (2017) studied UK infrastructure megaprojects and how the project setting affects digital delivery and discussed how the complex institutional forces affected the project setting of these megaprojects. This chapter navigates across the infrastructure megaproject setting focusing on the impact of institutions and agency upon digital innovation.

17.2.4 Knowledge gap

By viewing innovation as a social phenomenon, studies show that it is deeply embedded in its historical and institutional context. Thus, by exploring its embeddedness, insights are generated into how it works as an STS. The emphasis on infrastructure megaprojects as an organisational lens provides a novel view of innovation as an STS and helps frame the phenomenon of digital innovation. Additionally, individual actors and firm-centric agencies may facilitate wakes of innovation (Boland, Jr *et al.*, 2007) and use formal and dynamic approaches to influence their networks. By mapping the relationships among actors, institutions, megaprojects and digital technologies, one can infer their role in transitions of digital innovation. Rather than focusing on the organisational view of developing innovations (Hobday, 1998), this chapter focuses on the institutional structure (hierarchical or networked), agency and processes that influence innovation. It does so by using Geels' (2004) MLP theoretical lens of innovation through the interplay of (1) rules and institutions, (2) actors and social groups, and (3) digital technologies and STS. Figure 17.1 shows the theoretical framework of the chapter as a loosely coupled system of MLP within the area of problematisation: UK construction.

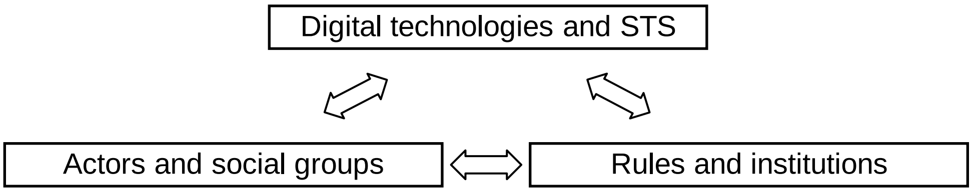

Figure 17.1 Theoretical setting of the chapter framed around MLP: (1) actors and social groups, (2) rules and institutions, (3) digital technologies and STS (infrastructure megaprojects) based on Geels (2004)

17.3 Research method and data

17.3.1 Methodological rationale

The study setting looks at digital innovation in infrastructure megaprojects. Through the research setting of institutional intervention and megaprojects in the UK, the mutually constitutive relationship between digital innovation and its institutional context is unpacked. The UK has adopted an institutional interventionist mode in relation to innovations in the built environment (Papadonikolaki, 2017). Digital innovations are catalysed by both responsive and anticipatory mechanisms (Morgan, 2019). Data for the case was collected using narrative literature reviews, anecdotal data from industry leaders, policy makers and practitioners who were directly involved in the megaprojects, standardisation and publicly available archival data. By combining retrospective and contemporary data in this way, a longitudinal study was generated (Pettigrew, 1990). The data was then analysed using comparative, synthetic strategies. In this longitudinal case study (Leonard-Barton, 1990) of digital innovation in infrastructure megaprojects, the chronological description serves as a structure to frame the theorization process. Through the theorising mechanism of induction, the researchers formulated propositions on various institutional roles in digital innovation in UK infrastructure megaprojects through the interplay of discursive analysis and empirical data to develop the study narrative.

17.3.2 Methods for data collection and analysis

For this chapter, data was collected on selected megaprojects in the UK, spanning from 1985 to contemporary, ongoing projects, thus covering a substantial time period in the process of digital innovation in UK construction industry. The UK construction sector was the main case study and featured six case sub-units (Yin, 1984) of infrastructure megaprojects. Four completed and two current infrastructure megaprojects or "breakthrough projects" (Shenhar and Dvir, 2007; Wheelwright and Clark, 1992[AQ2]) were studied, namely High Speed 1 (HS1) or the Channel Tunnel Rail Link, Heathrow Terminal 5, the London Olympics, Crossrail, Thames Tideway and High Speed 2 (HS2).

Data were collected through desk research, including government reports, industry reports, standards and mandates. Additionally, publications in academic journals provided useful insights into structuring the narrative. The data collected using desk research (Petticrew and Roberts, 2008) provided an unbiased and replicable account of the existing substantial body of literature relating to the institutional setting, the role of individual agency, and digital innovations in these megaprojects. Due to the emphasis on an institutional lens, both grey and scientific literature were reviewed, consistent with a networked view of innovation in the context of construction. The data were analysed using Langley's (1999) recommendations for using synthetic strategies to analyse process data, as is appropriate for a longitudinal embedded case study comprising multiple sub-unit (Yin, 1984) megaprojects, institutional actors and key events. The predictive potential of such analysis (Langley, 1999) increased the potential value of the findings.

17.4 Data presentation and findings

17.4.1 Framing digital innovation in UK infrastructure megaprojects

The chronology of events was divided into several distinct stages by drawing upon findings by Morgan (2019), who studied how the UK industry improvement agenda influenced organisational change in a consulting firm through a longitudinal study. Critical events in each segment were identified and used to explore the role of key stakeholders in digital innovation and its standardisation (Leonard-Barton, 1990), following a presentation of key events and the interplay among (1) actors and social groups, (2) rules and institutions, and (3) digital technologies in megaprojects as STS according to MLP (Geels, 2004). In chronological order, the six projects identified for detailed study were The Channel Tunnel Rail Link (CTRL or HS1) which ran from 1985 to 1994); Heathrow Terminal 5 (1999–2008); the London Olympics 2012 [AQ3](2005–2012); Crossrail (2008[AQ4]–2018); Thames Tideway (2012[AQ5]–2023) and High Speed Two (or HS2) (2017–2026). The last two projects – Thames Tideway and HS2 – are ongoing at the time of writing; the other projects are completed.

In particular, the key events that provided temporal breakpoints were used to signpost the transitions of digital innovation through the pathways of reconfiguration, transformation, reconfiguration and re-alignment as outlined and analysed through an MLP lens in the next sub-sections. The ensuing analysis is organised per transitions and (1) actors and social groups, (2) rules and institutions, and (3) digital technologies and STS through the setting of megaprojects. However, as the MLP framework targets the interplay among these factors, the respective subsections make linkages to other of the three categories (institutions, actors and technologies) where appropriate as the dynamics of the UK construction are interconnected. Table 17.1 summarises the transition pathways as a "nuanced analytical apparatus to analyse unfolding transition processes" (Geels *et al.*, 2016) and specific findings are further presented in the ensuing sections.

Table 17.1 Transition pathways of digital innovation in UK construction along the three categories (institutions, actors and technologies), based on framework by Geels (2004)

Transition pathways	*Rules and institutions*	*Actors and social groups*	*Digital technologies and STS*
Substitution (–1998)	Limited institutional change from government-sponsored industry reports calling for change No rules developed	Firms become sporadically aware of the need for change No new entrants	In complex megaprojects, the need for technological change is accentuated Digital tools complement and substitute existing tools
Transformation (1998–2011)	Institutional change by sponsoring an institutional and collaborative project to inspire change Project outputs become basis of British standards	Incumbents reorient incrementally by adjusting their processes New government-sponsored groups and communities to drive change emerge	Incremental progress in existing technologies Incorporation of symbiotic niche innovations and add-ons that change the processes
Reconfiguration (2011–2016)	Substantial institutional involvement and legitimization via mandates for new technology in public procurement Issuing of suites of standards to lead	Incumbent firms reorient substantially to new technology and business model New alliances between incumbents and new entrants	From initial add-ons to new hybrids of new and existing technologies Partial or full technical substitution of tools that brings

	change		new processes
Re-alignment (2016–)	Institutions are disrupted from the impact of new technology mandates Need to change so as to internalize new processes	Firms have fully reoriented Incumbents collapse because of landscape pressure Opportunities for new entrants	Decline of old technologies create space for competing innovations Processes are disrupted

17.4.2 Pathway 1: Calling for cultural and technological change – Substitution (up to 1998)

17.4.2.1 Rules and institutions during substitution

The improvement agenda in UK construction sector has included visions of partnering, supply chain management and a lean philosophy, all of which were imported from other sectors such as aerospace and manufacturing (Bresnen and Marshall, 2001) and tested in infrastructure megaprojects. This confirms research that finds that the construction industry has a tradition of importing and not producing technological innovations (Pavitt, 1984). Scholars challenged the extent to which such innovations are indeed applied and effective in construction (Fernie and Tennant, 2013), accusing industry strategists of uncritically adopting "management fashions" (Green, 2011) and defending business as usual.

17.4.2.2 Actors and social groups during substitution

Through an institutional lens, two inter-connected reports were instrumental in influencing the institutional context of innovation in the UK construction sector. The Latham (1994) and Egan (1998) Reports called for increased integration and collaboration among the supply chain to improve industry performance. Improved performance and increased efficiency were recurring themes of both reports. The Latham (1994) Report, "Constructing the Team," criticised the industry for being adversarial, ineffective, fragmented, and with low value for money for the client and proposed the adoption of partnering to increase teamwork and collaboration (Latham, 1994). The Egan Report (1998), [AQ6][AQ7]"Rethinking Construction," followed the same logic and apart from cultural change was very keen to use digital technologies to improve construction performance.

17.4.2.3 Socio-technical systems during substitution

The Egan Report (1998) was an outcome of the Channel Tunnel project – the first seminal infrastructure megaproject in the UK construction sector – and strongly emphasised using digital technologies to improve processes. The technical complexity of the Channel Tunnel project (also referred to as High Speed 1 or HS1) pushed the boundaries of technological developments in the UK construction sector through information representation and modelling solutions and 3D design tools (Pöttler, 1992). Computer-based tools to deal with interoperability problems among different systems, such as cost management and procurement systems, were the main innovations of the project (Kelsey, 2019). The technological developments in this infrastructure megaproject echoed developments in automotive and aeronautical engineering in the mid-1980s and initiatives in the US for "building product model" definitions to exchange building information amongst Computer-Aided Design (CAD) applications (Eastman, 1999) that replaced error-prone human interventions.

17.4.3 Pathway 2: Reorienting towards new digital technologies – Transformation (1998[AQ8]–2011)

17.4.3.1 Rules and institutions during transformation

Simultaneously, as well as developing policy interventions, the UK government stimulated and facilitated innovation development and market diffusion of digital technologies through institutional projects (Holm, 1995). In the context of the construction sector, such a collaborative or institutional project (Holm, 1995) was the Avanti project (2001–2005), whose objective was to enable effective collaboration among teams through digital technology (Morgan, 2017). Avanti was an inter-institutional collaboration among the Department of Trade and Industry with the support of most of the largest UK construction firms, the International Alliance for Interoperability (IAI, now called BuildingSMART), universities and R&D departments. Such collaborative projects can implement improvement agendas' policies and share the vision when firms lack the confidence and means to invest in their own R&D. Around 2010 in the Victoria Station upgrade project, the team started using the Avanti standard to control information and increase people's trust in data and collaboration. Avanti's focus was on creating collaborative culture and providing processes and digital tools to enable collaboration in teams (Morgan, 2017) through the use of two-dimensional digital design. Avanti became the basis of the BIM British Standard BS1192 issued by British Standards Institution (BSI).

17.4.3.2 Actors and social groups during transformation

One of the first institutional projects to explore collaborative digital working in the UK, the Avanti project marks the beginning of the journey along the BIM maturity trajectory (Bew and Richards, 2008). Funded by the UK government in 2001 under its "Partners in Innovation" scheme, Avanti drew several major industry partners together to work on developing rudimentary shared work practices amongst project teams. Such practices were essential in enabling the collaboration required by digital technologies such as BIM. The project underlined the significant challenges and need for such practices to be developed. Such was the industry appetite for this that Avanti continued to be supported after government funding expired.

In 2006, the Avanti brand ownership was transferred to Constructing Excellence (CE), an industry body that was formed to implement the "Improvement Agenda" as laid out in the Latham and Egan Reports and started as the aggregator of several other industry bodies. It was concluded that despite these coordinated efforts from the two reports, the proposed improvements or innovation had not been readily adopted in construction. Almost two decades after the Egan Report (1998), the Wolstenholme *et al.* (2009) Report, 'Never Waste a Good Crisis," after collaboration with CE, reviewed the success of the 1994 and 1998 reports. Radical change came from the UK government mandated the use of the so-called Level 2 BIM on all public sector projects starting after April 2016 (GCCG, 2011). The Level 2 BIM is a concept developed by Bew and Richards (2008), which is relatively vague and specifies the use of 3D models in a collaborative way.

17.4.3.3 Socio-technical systems during transformation

Digital technologies also evolved along the years. The CAD tools used in the Channel Tunnel project were predecessors of BIM. Building product modelling advancements followed the long-standing debate on the computerisation and digitalisation of construction (Eastman, 1999). Contrary to widespread belief, BIM is not new; it is, in part, an outcome of evolving efforts by industry consortia, such as BuildingSMART, to standardise building information (East and Smith, 2016). In particular, megaprojects have a strong relationship with digital innovations and require collective action from organisations involved to "to overcome considerable resistance to new ways of working" (Davies *et al.*, 2009). Information directors and personnel moved from the Channel Tunnel project to the Heathrow Terminal 5 megaproject and informed the evolution of digital innovations there.

Throughout these megaprojects the language about digital innovation changed. For example, at Heathrow Terminal 5 the digital innovation that now is called BIM was referred to by Davies *et al.*

(2009) as a “single-model environment,” Heathrow Terminal 5 was the research setting of innovation studies in megaprojects by Davies *et al.* (2009) and their influential model of systems integration. This was developed in the later study by Davies and Mackenzie (2014), drawing on systems integration in complex projects, which are conceived as a “system of systems.” Another study drawing on the London Olympics megaproject found that the trajectories of learning had a legacy beyond the built assets created: on the individuals and professions involved (Grabher and Thiel, 2015).

Heathrow Terminal 5 was also a research setting for Harty (2005), who drew on the digital practices used there to find the “unbounded nature” of digital technologies, and direct attention to the important area of interorganisational working that continues to challenge construction practitioners and researchers today. In later work, Harty and Whyte (2010) drew on the same megaproject to observe the “hybrid practices” being employed by practitioners – a theme that persists in contemporary practice with digital innovations.

17.4.4 Pathway 3: Legitimising digital innovation – Reconfiguration (2011[AQ9]–2016)

17.4.4.1 Rules and institutions during reconfiguration

The first construction strategy to specifically ask for change in digital innovation, namely by adopting BIM, was the 2011 Government Construction Strategy (HMSO, 2011). This strategy defined the objective that the government “will require fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016” (Office, 2011). [AQ10]Following the announcement of the mandate in 2010, the British Standards Institute (BSI) issued the suite of Publicly Available Specifications (PAS) number 1192. The PAS1192 contained six parts in total, published between 2013 and 2015. It specified the use of a Common Data Environment (CDE) – an online data sharing platform – how Asset Information Model (AIM) should be created and operated, facility management, safety and security implications of built assets (preparing the ground for BIM Level 3 mandate) and health and safety.

In 2013, the government issued “Construction 2025: Industry Strategy,” reaffirming the strong position with regards to BIM and digital way of working in the built environment and emphasising a joint commitment to the BIM vision and programme through partnership between government and industry and close collaboration of these two institutions. The visions further explained the firm stand in ensuring all centrally (governmentally) procured projects would be delivered through a BIM-based approach, eventually leading to a wider offsite manufacturing strategy. In 2016, the 2016–2020 GSC was issued by the cabinet Office and the Infrastructure and Projects Authority (IPA), which built upon the 2011 strategy, emphasising on BIM and Digital Construction as “an important part of the strategy and is helping to increase productivity and collaboration through technology” (Office, 2016), [AQ11]as well as the reliance on infrastructure megaprojects for digitally transforming the sector.

17.4.4.2 Actors and social groups during reconfiguration

In support of the mandate, the UK government created the UK BIM Task Group, a government-funded group managed by the Cabinet Office, in 2011. The BIM Task Group included practitioners seconded by their employers to support the success of the UK BIM Level 2 mandate. The UK BIM Task Group was funded until 2016 and later disbanded to form another Task Group to work on the BIM Level 3 mandate of “Digital Built Britain” (HMG, 2015). After it was disbanded, some of its members formed the UK BIM Alliance, which was publicly funded until 2017 to continue the efforts for increased adoption and implementation of BIM.

17.4.4.3 Socio-technical systems during reconfiguration

The Wolstenholme *et al.* (2009) Report directly influenced the Crossrail project, as Andrew Wolstenholme was the chief executive of this infrastructure megaproject. [AQ12]The innovation strategy that followed at Crossrail has been the subject of considerable scholarly and practitioner attention (DeBarro *et al.*, 2015). The longevity and institutional pluralism of Crossrail (2008–2018) made it an ideal vehicle to study the interrelations between megaprojects, institutions and agency. Senior managers from London Olympics (2005[AQ13]–2012) worked in Crossrail and transferred the ideas of digital change.

Crossrail originally specified the need for two-dimensional deliverables but evolved to develop 3D digital deliverables throughout its duration. Whereas it started well before the UK BIM mandates, it is one of the first UK projects to become PAS1192-compliant and use BIM as a digital platform for other innovations, such as laser scanning, using unmanned aerial vehicles (UAVs), drones, virtual reality (VR) and augmented reality (AR). The movement of ideas and leadership around digital innovation that took place was clearly evident. Andrew Wolstenholme, Chief Executive of Crossrail, explained about the inception of a BIM Academy in partnership with Bentley software (Munsi, 2012): "The Academy will support the Government Construction Strategy by increasing the use of BIM in the construction industry and creating a lasting legacy of best practice in innovation. The training received at the Academy will also help contractors use the knowledge and skill gained here on other major projects such as HS2."

17.4.5 Pathway 4: Renewing megaprojects via digital innovation – Re-alignment (2016–ongoing)

17.4.5.1 Rules and institutions during re-alignment

Following the enforcement of the 2016 mandate, the government stepped back to enable the industry to take the lead. However, the industry has not progressed fast enough to follow up on the mandate. In 2018, the UK PAS1192 was adapted at a European level and translated into ISO 19650 which shows that the UK leads standardisation of digital innovations in construction at an international level.

Recently, the Farmer (2016) Review "Modernise or Die," commissioned by the Construction Leadership Council at the request of the UK government, resonated with Wolstenholme *et al.* (2009) regarding (1) productivity losses and (2) lack of collaboration, additionally highlighting (3) lack of innovation and (4) skills shortage as persistent issues of construction. The Farmer (2016) Review called for urgent action in light of the newly-announced megaprojects pipeline in London and the southeast of England. The UK government initialised the standardisation process and further organised innovation activities for digital technology development and diffusion.

17.4.5.2 Actors and social groups during re-alignment

Although the institutions have ceased rule-setting activities since the mandate of 2016, organizations started slowly to fully de-align and re-align. Due to the new mandates for digital delivery, Lobo and Whyte (2017) found that contractors involved in megaprojects aligned the project set-up with their existing capabilities and reconciled differing agendas and capabilities in collaborating firms across the project ecology. Nevertheless, the five years from 2011 to 2016 was a short amount of time to change the industry mindset and more leadership was needed. Despite the leadership from the central UK government, the local government did not effectively drive the mandate, as there were less influential publicly procured projects, such as infrastructure megaprojects to drive digital innovation outside London and the southeast of England.

17.4.5.3 Socio-technical systems during re-alignment

The digital shift required collective action from companies across the supply chain and collaborating would need to be more substantial. For example, in pilot projects organised by the UK government's Ministry of Justice, such as Cookham Wood Prison, a two-stage open book procurement model BIM-based delivery, the supply chain – from suppliers to operators – was involved in dialogue very early on in the design stage to be able to co-create the project and collaborate effectively thereafter.

Senior managers from London Olympics (2005–2012), after working in Crossrail (2008–2018), were moved to the HS2 project (2017–2026). Both these past projects had a strong emphasis on passing legacy to newer megaprojects. Building upon developments from previous projects, the HS2 project aims to gather knowledge and mobilise it to construct the digital twin of the asset, that is a digital asset mirroring the physical infrastructure and able to simulate scenarios. It is expected that with the green light for HS2 in early 2020, the digital legacy of infrastructure megaprojects will support higher collaboration among government departments, with other major infrastructure programmes and professional institutions, to develop standards and make sure that UK government requirements can be met by the supply chain.

The infrastructure megaprojects studied in this chapter are marked not only but their innovative use of digital technologies within the project but by a growing awareness of the digital legacy they create. For example, the HS2 project is looking to redefine digital innovation in the UK construction sector by looking to develop competences not just limited to BIM but about data management in a broader sense. However it is also pioneering solutions that benefit the entire industry and are aimed to create lasting change such as its BIM upskilling platform (HS2, 2019). Similarly, Thames Tideway – a major infrastructure project that will replace London's ageing sewage structure with 25 km of new tunnel and the creation of new public spaces along the Thames – is heavily involved in institutional initiatives to create a digital learning legacy for the construction sector.

17.4.6 Mapping multi-level transitions of digital innovation in the UK construction sector

Digital innovation in the UK construction sector has been associated with various evolving technologies such as CAD and BIM, described previously. BIM is not only a domain of digital artefacts but has historical roots in the long process of structuring and standardising building information across the construction sector (Laakso and Kiviniemi, 2012). [AQ14]As seen through the chronology of the MLP transitions in the previous sections, BIM is an evolving concept and scholars and practitioners move towards more broad descriptions of BIM, such as "Building Information Management" (Becerik-Gerber and Kensek, 2009), "digitally-enabled working" (Dainty *et al.*, 2017), digitisation (Morgan, 2017) and digital innovation, to capture numerous associated innovations.

Drawing on the above data, indicative findings about the transitions of digital innovation across UK construction are mapped below in Figure 17.2, which plots (1) rules and institutions, (2) actors and social groups and (3) digital technologies and STS through the lens of megaprojects, against the timeline of digital innovation in the construction sector following on the theoretical lens of Figure 17.1. This graphic visualises the interrelations among policy (rules and institutions), champions of change (actors and social groups) and digital innovations used in infrastructure megaprojects (digital technologies and STS).

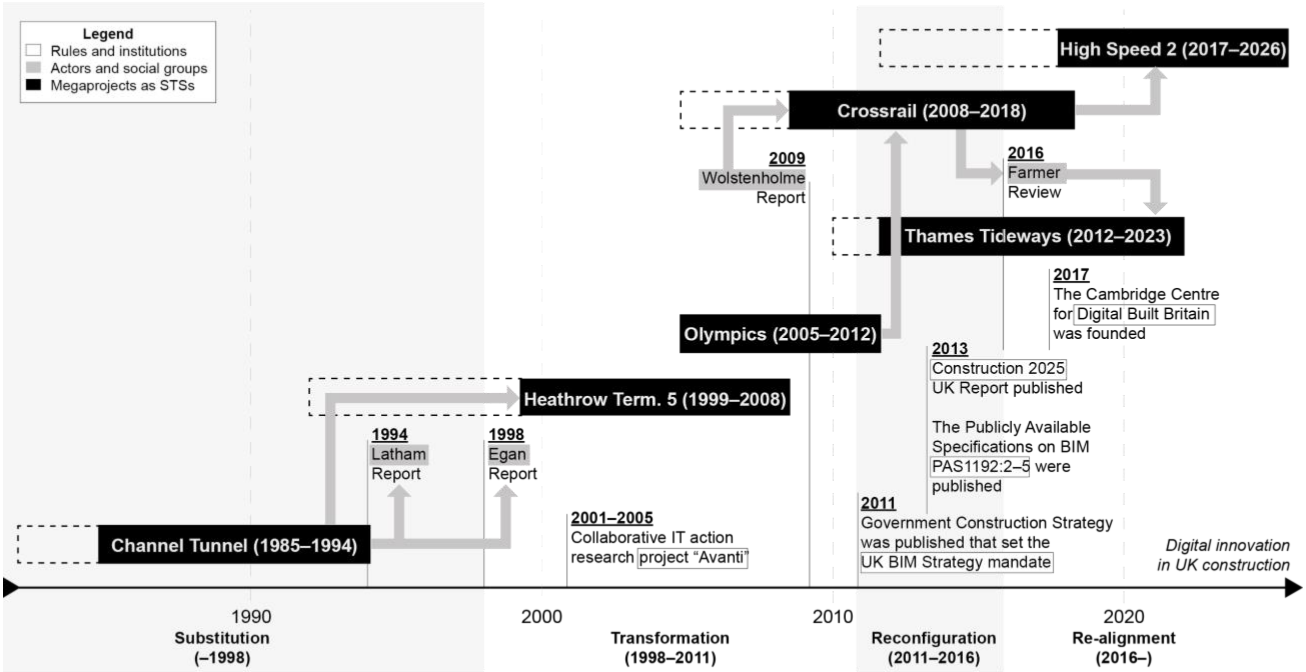

Figure 17.2 Timeline of digital innovation in UK construction influencing and being influenced by institutions, actors and megaprojects as socio-technical systems (STS) of digital innovation

17.5 Discussion

17.5.1 Megaprojects as niches for digital innovation

The authors drew on descriptions of megaprojects and institutional theory to identify six megaprojects for this chapter. First, Lundin and Söderholm (1995) described megaprojects as having temporal character but also of institutionalised termination, and as being both fluid and strategic. Hence, from the data it can be seen that megaprojects, with a range of organisations and institutions involved, can also be described as institutional projects that influence transition pathways of digital innovation. At the same time, megaprojects, due to their empirical richness, were ideal instances of socio-technical systems (STS) to show the evolving digital technologies through Geels' (2004) multi-level perspective (MLP) analytical lens. Holm (1995) defined institutional projects as political projects that engage various institutions by necessitating collective action to generate new institutions of political actors. The data revealed the "digital legacy" that megaprojects' leaders were keen to leave, as shown by Wolstenholme (Munsi, 2012) and sources about HS2's digital legacy.

The findings reveal the relation among institutional regulation, digital innovation and UK infrastructure megaprojects. First, it was revealed that the institutional push for digital innovation was detached from relevant technological emergence and therefore the reactive standards issued and the responsive mechanisms (Morgan, 2019) were not fully aligned with the continuously evolving status of digital innovation in UK infrastructure megaprojects. This can be seen through the scarcity of pilot projects to marshal digital innovations and the reactive compliance to digital innovation standards for Crossrail project – albeit ultimately successful. This chapter challenges the timing of regulation, standardisation and its stability, which differs among anticipatory, enabling and responsive standards (Morgan, 2019), in aligning the production system with the new technologies in the UK construction sector. Second, the chapter highlights the importance of influential social actors moving across infrastructure megaprojects and institutions and influencing digital innovation. The boundary-spanning capabilities of such social actors who transfer knowledge across domains

(Koskinen, 2008; Levina and Vaast, 2005) supported digital innovation in infrastructure megaprojects.

Nevertheless, the industry still struggles with innovation efficiency (see Table 17.1). The authors suggest that the UK construction industry needs to set up an open innovation paradigm towards the creation of anticipatory standards open and flexible enough as to realise the promise of digital innovation. Some evidence of relevant change can be found in the recent effort called “Project 13,” an industry-led collaborative endeavour, seeking to develop a new business model, based on an enterprise, not on traditional transactional arrangements, to improve the UK construction sector (Group, 2017). This open innovation initiative is bringing changes not only to product-oriented sectors but also services (Chesbrough, 2011). Among the ambitions of the Infrastructure Client Group (ICG) (Group, 2017) is to “establish standards that all ICG members will sign up to and enforce across all of their projects.”

17.5.2 Identifying transition pathways of digital innovation in the UK construction sector

This chapter set out to explore the relation between megaprojects and their institutional setting to understand how their evolution shapes transition pathways of digital innovation. Addressing this research aim, the authors framed the chapter around Geels’ (2004) MLP: (1) actors and social groups, (2) rules and institutions, and (3) digital technologies and STS and context: UK infrastructure megaprojects. Although MLP has been used in the past to define the transition pathways where different countries belong, e.g., in the case of comparing Germany and the UK as to low-carbon electricity transitions (Geels *et al.,* 2016), this chapter due to its longitudinal character revealed the evolving interplay of institutions, actors and technologies in UK infrastructure megaprojects.

Drawing on Langley’s (1999) temporal bracketing strategy, this chapter identified four distinct transition pathways that mark the evolution of digital innovation in the UK construction sector: substitution, transformation, reconfiguration and re-alignment. As shown in the findings each of these phases are distinguished by distinct events and interactions at multiple levels. By undertaking a longitudinal process study of the industry, a long-term view of digital change is afforded. The digital evolution of the industry is particularly important in its current transition through “re-alignment.” This chapter suggests that infrastructure megaprojects play a significant role in affording digital evolution, and that its effects influence and are influenced by events at multiple levels: social groups, rules and institutions, digital technologies and STS. Recent industry initiatives illustrate the convergence among these – for example, in initiatives such as Project 13; in HS2’s BIM upskilling platform – and harness the significant influence that megaprojects have in driving digital innovation. However, the rapid pace and extent of digital transformation in the construction industry seen in recent years suggests that such initiatives need to become more prevalent and timelier.

17.5.3 Contribution to theory and knowledge

The contribution of this chapter is at two levels. First, at a middle-range theory level, the chapter added to the knowledge base of digital innovation in construction by structuring and synthesising an alternative view of existing and new empirical data on digital innovation in infrastructure megaprojects. Through this longitudinal study of over 30 years, the institutionalisation of digital innovation is a central finding that calls for rethinking and re-organizing institutions and infrastructure megaprojects. From a multi-level perspective (Geels *et al.,* 2016), four discrete transition pathways (substitution, transformation, reconfiguration and re-alignment) were defined through three major (standardisation or regulatory) events. Among these milestones, standardisation and regulation abounded, specifically through the Avanti project (2001–2005) and the suite of

PAS1192 standards (2013–2015) and accompanied digital innovation in infrastructure megaprojects as STS.

Second, at a general management theory level, the chapter added to our understanding of digital innovation and infrastructure megaprojects in an analytic way that revealed the interdependences among institutions through the lens of MLP: institutions, actors and technologies as "analytical apparatus to analyse unfolding transition processes" (Geels *et al.,* 2016). Additionally, through MLP, although the areas of (1) rules and institutions and (2) actors and social groups are typically self-explanatory in MLP studies (Geels *et al.,* 2016; Geels, 2004) but technologies and socio-technical systems (STS) are less so. To this end, this chapter extended the MLP analytical lens by presenting infrastructure megaprojects as STS and niches where actors and technology interact in joint endeavours. Eventually, understanding the politics at a macro level of networked innovation (Swan and Scarbrough, 2005) can support the understanding of organisational innovation at a micro level.

17.5.4 Managerial implications

The chapter has several implications for practitioners. Table 17.1 shows two main categories of implicated parties: institutions, such as government bodies, and actors, such as practitioners. First, with regards to institutions, the chapter outlined how the different regulatory and standardisation efforts impact the sector, as seen by such events acting as defining breakpoints of four discrete transition pathways (substitution, transformation, reconfiguration and re-alignment). Institutional projects, such as Avanti, that bring the sector together in an open innovation paradigm are useful vessels to marshal collective expertise and action to influence change and socio-technical transitions. Recently, infrastructure megaprojects also form institutional vessels that broker change.

Second, at a practitioners' level, the chapter has implications for managers of incumbents and new entrants in the market (see Table 17.1). Managers of incumbent firms need to reorient substantially by adopting digital technologies and new business models, e.g., "from transactions to enterprises," In addition, they should be open to form alliances, such as Project 13, between incumbents and new entrants to co-develop standards and respond to digital transition. As the sector is under disruption, managers of new entrants and reoriented incumbents with novel business models stand to gain more from digital innovation.

17.6 Chapter summary

The use of the multi-level view on the process of digital innovation in the UK construction system offers an alternative view on the process. Digital innovations are produced and shaped by the interplay of institutional and organisational factors. The chapter discusses the role of actors who moved across infrastructure megaprojects and institutions and influenced digital innovation in socio-technical niches. The chapter contributes to our understanding of the importance of infrastructure megaprojects as potential niches of digital innovation. Another emergent finding relates to the role of institutions and actors in leading digital innovation through these infrastructure megaprojects. From the data presented, four discrete transition pathways of digital innovation (substitution, transformation, reconfiguration and re-alignment) emerged the last few decades due to varying interactions among institutions, actors and infrastructure megaprojects. Digital innovation became legitimised through standards emerging from infrastructure megaprojects.

The practical implications of this chapter are to reveal the transition mechanisms that lead to digital innovation. Understanding the inter-relationships among infrastructure megaprojects, institutions, actors and how they influenced digital innovation will help prepare for and identify patterns and opportunities for managing the unprecedented pace of emerging digital technologies that influence the construction industry. Additionally, the chapter showed that infrastructure megaprojects due to the range of organisations and institutions involved could also be described as niches. Apart from the construction sector, these findings are valuable for other sectors, because the built environment allows us to study this relatively slow transformation over three decades and identify mechanisms and inter-relations that are hardly noticeable in other sectors, where the pace of innovation is more accelerated.

17.6.1 Chapter discussion questions

After studying this chapter, discuss the following questions:

1. What is digital innovation, and how it is different from innovation?
2. How do actors, institutions and infrastructure megaprojects influence digital innovation?
3. What is the extent to which infrastructure megaprojects support digital innovation?
4. What is a socio-technical system view and multi-level perspective?
5. How can the public sector support digital innovation?
6. What key transitions can be distinguished in digital innovation in UK construction?

17.7 Case study: Tideway's digital evolution: How digitalisation drives productivity

One of the current megaprojects considered in this chapter, Thames Tideway Tunnel, supplements London's existing Victorian sewage network. Running 25 kilometres through central and greater London, 24 construction sites exist across the capital spanning from Acton in the west to Stratford in the east. The tunnel will enhance the lives of many Londoners, as well as the natural ecosystems of the Thames itself, by ensuring sewage is not pumped directly into the river. Like earlier infrastructure megaprojects, it played a significant role in the development of institutional policies and standards in the UK construction industry. Further, many of its key actors had gained experience at Crossrail and other preceding megaprojects.

What is distinct about Thames Tideway is the rate at which digital change is occurring during its design and construction. In the five years since construction of Thames Tideway began, the potential of digital technologies to transform almost all aspects of professional and personal life has accelerated radically. It is no surprise then that the approach to digital technologies in Tideway has also evolved. Not only has this enabled the contractors to meet their contractual obligations to the client and supply digital records of the built asset upon handover, it had also given rise to many other digital innovations. With the project's complex supply chain and its numerous stakeholders it had to liaise with, this coordination and communication was invaluable. For instance, 3D models were being used extensively to improve the quality and quantity of communication and coordination with a diverse set of stakeholders. Regular design reviews used a walk-through of the model and enabled the team to visualise new issues that demanded attention. Models enabled communication with local residents, who could easily see planned and completed work. 3D models made available for consultation by all contractors at five construction sites had been generated from real time data. Increasingly models had been developed to include 4D elements (incorporating time into 3D) to help with challenges around logistics and construction sequencing.

As well as modelling, numerous other digital innovations were being used to help management and to solve engineering challenges. For example, drones were being used to survey the existing sewers, thus saving staff from working in an extremely unsafe and unknown environment. These types of digital innovations were likely to become increasingly important as the project entered its peak delivery phase. Much had also been achieved through relatively small interventions and investments: for example, the falling cost of mobile technology meant that this could be made available to a larger number of on-site staff. The recent introduction of Flowforma was already being used to digitise the “starters and leavers” process across the joint venture of Costain, VINCI, and Bachy Soletanche (CVB), thus enabling a previously problematic business process to be performed more accurately and quickly.

However, although there was good evidence that digital technologies were having numerous benefits across the project, the challenge remained of how to prove the value of digital innovation was becoming more pressing. With an increasing number of digital technologies available, how could their value be measured and managed?

17.7.1 Case discussion questions

1. How can digital innovations improve productivity across the Tideway Alliance?
2. How can we measure how digital technologies drive productivity gains?
3. Can you think of the advantages and disadvantages of doing so?
4. What measures would you take to encourage digital innovation in a megaproject?

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