Projects as a speciation and aggregation mechanism in transitions

Bridging project management and transitions research in the digitalization of UK architecture, engineering, and construction industry

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Projects as a speciation and aggregation mechanism in transitions: Bridging project management and transitions research in the digitalization of UK architecture, engineering, and construction industry.

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ABSTRACT

Sociotechnical transitions are mostly seen in the literature as processes where actors and technologies in small niches peripheral to an organizational field, accumulate momentum, scale up, aggregate, and eventually bring about large-scale regime change. Foundational examples include the British transition from sailing ships to steamships and the American transition from traditional factories to mass production. Herein lies a paradox, transitions concern large scale system change for example transition to electric cars or renewable energy, but large-scale options for technological change driven by incumbents have received less attention in transitions research. This is an important opportunity for transition research to draw on the literature of project management research on large-scale projects. We bridge transitions research and project management research by exploring speciation and aggregation from both perspectives. We illustrate how this bridge may be instantiated drawing on published research and interviews on six megaprojects that have been instrumental in the digital transformation of UK construction: (i) the Channel Tunnel Rail Link, (ii) Heathrow Terminal 5, (iii) London Olympics, (iv) Crossrail, (v) Thames Tideway and (vi) High Speed Two. The speciation of digital technology seeds the process of aggregation and UK industry transition which is driven by incumbents at the organizational field core and ripples outward to its periphery. This is a reverse process to the one mostly considered in transition research where change initiates in small niches peripheral to an organizational field and propagates until it eventually brings about large-scale change to its core.

1. Introduction

Sociotechnical transitions are long-term evolutionary processes of system change that span multiple temporal and spatial scales, they involve multiple actors and factors, and their study has developed into a substantial research program (Köhler et al., 2018, 2019). Transitions take place at the level of the organizational field level which by definition encompasses organizations e.g. key suppliers, resource and product consumers, regulatory agencies, and other organizations that produce related services or products, which in their totality constitute an identifiable area of institutional life (DiMaggio and Powell, 1983; Geels and Schot, 2007; Scott, 2014).

Herein lies a twofold paradox (Poole and van de Ven, 1989). First, transitions research concerns organizational field change, but it has not so far integrated insights from project management (PM) research which precedes it by several decades. Projects are ubiquitous and constitutive elements of organizational change processes (Gareis, 2010; Lundin et al., 2015; Vuorinen and Martinsuo, 2018). Organizations engage in project-based organizing and learning to change and overcome organizational inertia (Brown and Eisenhardt, 1997; Sydow et al., 2004; Sydow and Windeler, 2020). This is done through internal projects (Riis et al., 2019) or large interorganizational projects (Sydow and Braun, 2018; Tee et al., 2019), that are also embedded in more permanent, systemic structures such as organizational fields (Dille and Söderlund, 2011; Manning, 2008; Sydow and Braun, 2018; Sydow et al., 2004).

Second, transitions are large scale system change processes (Geels et al., 2017), but large-scale projects that deliver large scale technological options receive less attention than small scale options in

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transitions research (Geels, 2020; Sovacool and Geels, 2021; Turnheim and Geels, 2019).[1] Nevertheless, such large projects are of increasing global relevance and potential impact in transition processes due to their number, size, cost, and advanced technologies (Flyvbjerg, 2016, 2017; Flyvbjerg et al., 2003; Roehrich et al., 2024). More importantly, large projects are carried out by large industry incumbents at the centre of the organizational field network who coordinate and orchestrate their network of project partners (Dhanasai and Parkhe, 2006; Hobday et al., 2005; Roehrich et al., 2023, 2024), so we would expect them to have some impact on sociotechnical system interactions and transitions processes as well.

In this paper, we bridge transitions research and PM research and provide the basis for bidirectional exchange between the two communities of scholars and corresponding literatures. We, thus, heed the calls for transitions research on projects and organizational and management research (Sovacool and Geels, 2021; Sovacool et al., 2022; Geels, 2011), similar remarks made on the potential for cross fertilization between transitions research and innovative project-based organizing (Davies, 2014; Davies et al., 2018, 2023; Geraldi and Söderlund, 2023; Lenfle and Söderlund, 2022), and the notion that projects must be considered as multi-level, socio-technical ventures embedded in complex institutional settings (Biesenthal et al., 2018; Biesenthal and Wilden, 2014; Morris and Geraldi, 2011).

The paper establishes a bridge between transitions and project management research by considering interorganizational projects as a key middle range mechanism (Anderson et al., 2006; Davis and Marquis, 2005; Packendorff, 1995; Papachristos, 2018) through which organizational change may aggregate from one organization to the organizational field level. This bridge between transitions and project management research is instantiated in the case of digitalization transition of UK architecture, engineering, and construction (AEC), which focuses on six megaprojects (Davies et al., 2009). They are chosen because their large scale makes more evident issues that AEC faces: fragmentation, coordination, project design and delivery. The consensus view in UK industry reports is that these challenges must be addressed (Armitt, 2013; Egan, 1998; Farmer, 2016; Latham, 1994; Wolstenholme et al., 2009). The solution to these comes with the entry of software firms and the introduction and use of digital technologies from US defence and aerospace industry to AEC (Chasen, 1981; Llewelyn, 1989; Morris, 2013).

Speciation, the introduction and use of a technology in a different application domain (Astley, 1985; Cattani, 2006; Levinthal, 1998), is a fairly common pattern in technology development and commercialization (Adner and Levinthal, 2002). It leads through path dependence (David, 2007; Sydow et al., 2009), to knowledge innovation and capability recombination for which projects by their very nature serve as ad hoc milieus (Brady and Davies, 2004; Davies and Brady, 2000; Grabher, 2004; Gruber et al., 2012; Hobday, 1998, 2000; Lavie, 2006; Lobo and Whyte, 2017). Incumbents that lead projects in the AEC industry, adopt these digital innovations to meet project requirements and they also adapt to them organizationally (Davies et al., 2009; Dodgson et al., 2015; Morgan, 2019; Whyte, 2019). In this way organizational changes diffuse to their network of project partners as well.

Activities in each project aggregate over time with the accumulation and codification of knowledge, technology standards and selection criteria. The accumulation of interactions between incumbent project partners and digital technology suppliers changes the project related and organizational practices they help constitute (Harty, 2005; Harty and Whyte, 2010; Morgan, 2019), and drives the coevolution of organizations, their competences, digital technology innovation, and knowledge (Ciarli et al., 2021; Leonard-Barton, 1988; Orlikowski, 1992). Through their mobility, senior managers in incumbent firms act as brokers of knowledge (Argote et al., 2022; Argote and Ingram, 2000; Burt, 2004). They span the project networks of successive projects (Tushman and Katz, 1980; Tushman and Scanlan, 1981), through which the co-adaptation of innovations and organizations extends to other industry partners in the organizational field, and along with the emergence of standards, they transform the organizational structure and practices of project partners towards more integrated collaboration (Eastman et al., 2011; Sebastian, 2011). Thus, change led by incumbents permeates their project networks and shapes change in the AEC.

The combination of three characteristics makes our case noteworthy. First, the six projects have been the subject of considerable attention in PM research e.g. Davies et al. (2009), but they have not yet been treated as part of a single longitudinal study of industry level change from a PM or transitions research perspective. Our approach in this paper illustrates the value of PM research for transitions research, and at the same time the application of a transitions perspective on PM research that extends beyond the confines of research on single projects (Engwall, 2003). The case illustrates projects as middle range mechanisms (Anderson et al., 2006; Davis and Marquis, 2005; Packendorff, 1995; Papachristos, 2018) of speciation and aggregation processes in transitions research that can potentially be the basis to establish multi system interactions as well (Papachristos et al., 2013).

Second, this transition process exhibits a speciation and aggregation pattern with the introduction of digital technologies from the US defence and aerospace industry into the AEC industry where they are applied and developed in successive projects led by industry incumbents. This process of change is driven by project-based networks where actors utilise knowledge, and engage in institutional entrepreneurship as they move from one project to the next (Battilana et al., 2009; Greenwood et al., 2011; Greenwood and Suddaby, 2006; Zietsma et al., 2016). With this process, change in the AEC industry proceeds from the core of the organizational field network to project subcontractors in its periphery (Abrahamson and Fombrun, 1994; Abrahamson and Rosenkopf, 1997). In contrast, in the archetypical transitions narrative (Geels, 2018; Geels et al., 2023a; Geels and Turnheim, 2022), the development of niches proceeds from the organizational field periphery to its core by sequential entry into ever larger market segments and transforms the dominant technologies, incumbent actors and regime(s) of rules that underlie system stability and reproduction (Fuenfschilling and Truffer, 2014; Geels, 2011; Genus and Coles, 2008).

Third, speciation and aggregation are necessary to understand the digitalization process, a combination which has received scant attention in project management or transitions literature (Geels and Raven, 2006; Naber et al., 2017; Smith and Raven, 2012), and is absent from research on multi system interactions though it occasionally hints to it (Andersen and Geels, 2023; Andersen et al., 2023; Papachristos et al., 2013). We provide the basis for further research on such processes and theorise this combination into a diagram (Langley and Ravasi, 2019; Swedberg, 2017; Weick, 1995b).

The remainder of this paper is organised as follows. Section 2 introduces the theoretical framework for the study of speciation aggregation from a transitions research perspective (section 2.2) and from a project management research perspective (section 2.3 and 2.4). Section 3 summarizes data and methods used in our research. Section 4 presents the case of digitalization transition in UK AEC. Section 5 relates the points raised in the paper to the transitions research and project management literature and outlines further avenues of exchange. Section 6 concludes the paper.

2. Theoretical background

The foundations of the bridge between transitions research and PM lie on five observations. First, the core pillars of transitions frameworks and research i.e. multi-level theorization of change and structuration theory (Geels, 2002, 2004), overlap with the core pillars for research on

[1] This paradox originates partially in the conceptualization of action as a micro level phenomenon and social structure as a macro level phenomenon in social theories (Poole and van de Ven, 1989).

Table 1
Cursory literature on the key corresponding concepts for project management and niche research.

	Niches	Projects
Network development	Boon et al. (2014), Diaz et al. (2013), Kern et al. (2015), Kivimaa (2014), Kivimaa et al. (2019), Musiolik et al. (2012), Raven and Geels (2010), Schot and Geels (2008a), Smith and Raven (2012), Verhees et al. (2013)	Aaltonen and Kujala (2010), Ahola (2018), Artto et al. (2016), Black et al. (2000), DeFillippi and Sydow (2016), Galvin et al. (2021), Grabher (2004), Laan et al. (2011), Linderoth (2010), Lundin et al. (2015), Manning (2017, 2010, 2008), Oliveira and Lumineau (2017), Pryke (2017), Sydow (2021), Sydow and Braun (2018), Wang et al. (2021), Winch (1998)
Actor alignment	Geels (2004), Heiberg et al. (2022), Kivimaa (2014), Kivimaa et al. (2019), Schot and Geels (2008, 2007), Smith et al. (2010), Turnheim and Geels (2013, 2012), Wittmayer et al. (2017)	Baiden and Price (2011), Briscoe and Dainty (2005), Dietrich et al. (2010), Dubois and Gadde (2002), Hoegl and Gemuenden (2001), Hoffman et al. (2020), Jacobsson et al. (2017), Lundin et al. (2015), Meng (2012), Suprapto et al. (2015), Vachon et al. (2009), Vrijhoef and Koskela (2000), Windeler and Sydow (2001)
Learning	Beukers and Bertolini (2021), De Kruijf et al. (2020); Geels and Deuten (2006), Goyal and Howlett (2020), Hoogma et al. (2002), Kemp et al. (1998), Schot and Geels (2008), Van Mierlo and Beers (2020), Van Poeck and Östman (2021), Voss et al. (2006)	Atkinson (1999); Brady and Davies (2004); Busby (1999), Cooper et al. (2002), Davies and Brady (2000), Grabher (2004), Keegan and Turner (2001), Koskinen (2012), McClory et al. (2017), Neale and Holmes (1990), Prencipe and Tell (2001), Scarbrough et al. (2004b), Williams (2008, 2003)
Knowledge transfer & codification	Bakker et al. (2015), Bergek et al. (2008), De Wildt-Liesveld et al. (2015), Geels (2004), Geels et al. (2008), Geels and Schot (2007), Hekkert et al. (2007), Markard and Truffer (2008), Smith et al. (2010)	Bendoly (2014), Bendoly and Swink (2007), Bishop and Gembey (1985), Buvik and Rolfsen (2015), Cohen and Bailey (1997), Daft and Macintosh (1981), Gann and Salter (2000), Koskinen et al. (2003), Lehtinen et al. (2019), Sense and Antoni (2003), Styhre et al. (2004), Zaheer et al. (1998)
Empowerment & Aggregation	Borghei and Magnusson (2018), Geels (2005), Geels and Deuten (2006), Naber et al. (2017), Raven (2007), Raven and Geels (2010), Smith et al. (2010), Smith and Raven (2012)	Davies (2004), Davies and Brady (2000), De Benedittis (2019), Esposito et al. (2021), Gann and Salter (2000), Grabher (2002), Hobday (2000), Kadefors (1995), Nobeoka (1995), Prencipe and Tell (2001)
Institutions, governance and structuration	Fuenfschilling and Binz (2018), Fuenfschilling and Truffer (2014), Geels (2004)	Ahola et al. (2014), Bechky (2006), Denicol et al. (2021), Hetemi et al. (2020), Manning (2010), Miller et al. (2001), Söderlund and Sydow (2019), Sydow and Windeler (2020), Windeler and Sydow (2001)

transformation processes in project-based industries: multi-level theorization of change (Gann and Salter, 2000; Geraldi and Söderlund, 2018; Lundin et al., 2015; Söderlund and Sydow, 2019; Sydow and Braun, 2018; Winch, 1998), and structuration theory (Bresnen et al., 2005; Floricel et al., 2014; Sydow and Windeler, 2020; Windeler and Sydow, 2001). Second, the proposition that transitions are embedded at the organizational field level (Geels and Schot, 2007), applies also to projects that also embedded in more permanent, systemic structures (Dille and Söderlund, 2011; Sydow and Braun, 2018), i.e. their associated organizational units, organizations, interorganizational networks and organizational fields (Manning, 2008; Sydow et al., 2004).

Third, PM literature argues that projects must be considered as multi-level socio-technical ventures embedded in complex institutional settings (Biesenthal et al., 2018; Biesenthal and Wilden, 2014; Morris and Geraldi, 2011). In this respect, PM research holds great potential for transitions research on the interplay of institutions, actors, and technology in projects due to their duration, pervasiveness, and institutional embeddedness (Brookes et al., 2017). Fourth, projects are ubiquitous and constitutive elements of organizational change processes (Gareis, 2010; Lundin et al., 2015; Vuorinen and Martinsuo, 2018). Organizations engage in project-based organizing and learning to change and overcome organizational inertia (Brown and Eisenhardt, 1997; Sydow et al., 2004; Sydow and Windeler, 2020), either through internal projects (Riis et al., 2019) or large interorganizational projects (Sydow and Braun, 2018). The implication is that project success and organizational change is best analysed in the context of a series of projects that organizations participate in, and broader institutional processes (Biesenthal et al., 2018; Dille and Söderlund, 2011; Engwall, 2003; Morris and Geraldi, 2011; Sense and Antoni, 2003), just as in transitions research, sociotechnical change is analysed in the context of a series of niches and broader institutional processes (Geels and Raven, 2006; Schot and Geels, 2008). Fifth, sustainability has been the mainstay of transitions research (Geels and Turnheim, 2022; Köhler et al., 2019), and it has received attention in project management research (Huemann and Silvius, 2017; Sabini et al., 2019). Nevertheless, there is noticeably less PM research on how projects can be organised and managed to contribute to bigger systemic transitions (Geels et al., 2023b; Sovacool and Geels, 2021).

In the rest of section 2, we introduce some necessary background to conceptualise transitions research in section 2.1, and then introduce speciation and aggregation from a transitions perspective in section 2.2. In section 2.3, we introduce project based organizational change, and in section 2.4 we provide the corresponding speciation and aggregation from a PM research perspective with an emphasis on project attributes (Fig. 2), in order to establish the conceptual bridge of PM to transitions research.[2] Section 2.4 concludes with Table 1 which provides a summary of key concepts and corresponding references in transitions and PM research.

2.1. Sociotechnical transitions: landscape, regime and niches

The sociotechnical regime is the central concept for the analysis of incumbent actors and their activities that reproduce system elements and modulate system stability and its trajectory (Geels and Schot, 2007). Regime refers to the underlying deep structures e.g. engineering beliefs, heuristics, established routines, industry standards, policy paradigms, visions, expectations, and norms of actors (Geels, 2011). A socio-technical regime is the instantiation of the most institutionalized core of an organizational field, the totality of key suppliers, resource and product consumers, regulatory agencies, and other organizations that produce related services or products, which constitute an identifiable area of institutional life (DiMaggio and Powell, 1983; Scott, 2014). The position of actors in the organizational field provides them with different institutional opportunities: central actors can use their power to shape institutions to their advantage (Greenwood et al., 2002); actors in the middle mostly conform to institutional pressures; actors in the periphery may find it easier to deviate from regime rules (Capponi and Frenken, 2021; Leblebici et al., 1991).

Peripheral niches act as 'protective spaces' with selection criteria that favour more new technologies compared to those in dominant regimes (Geels and Schot, 2007; Levinthal, 1998; Smith and Raven, 2012). For example, in the early 20th century wireless telephony developed

[2] Section 2 focuses on the Multi-Level Perspective. For the interested reader, the research agenda paper by Köhler et al. (2019) provides a more thorough presentation of the current state of transitions frameworks and literature.

where mobile communication was important i.e. in the maritime domain, not in land-based communication domain where there was already wired communication (Levinthal, 1998). Niche shielding from market forces is necessary for nascent technologies early in their lifecycle (Smith and Raven, 2012). Niche nurturing involves articulation of actor expectations and visions, development of social networks, and learning processes (Schot and Geels, 2008). The interaction of users with producers in niches, gives rise to mutual learning and expectation articulation processes (Kemp et al., 1998; Nill and Kemp, 2009). First order learning processes are important to improve the competitiveness of the technology along technical, market and user, cultural, infrastructure, industry, regulations, and societal dimensions (Kemp et al., 1998). Second order learning on developing alternative ways to value and support the niche is also important (Schot and Geels, 2008).

Sociotechnical transitions are non-linear processes that result from the interactions between niches, socio-technical regimes, and an exogenous socio-technical landscape (Geels, 2002; Rip and Kemp, 1998). Transitions research focuses on system interconnections and actor interactions that influence system stability and change, and provides a middle range theorization of how different interaction configurations result in different transition pathways (Geels, 2007, 2011). Transitions are multi-actor processes enacted by a range of actors and social groups from academia, politics, industry, civil society, and households which have their own resources, capabilities, beliefs, strategies, and interests (Köhler et al., 2019). Each type of actors brings a different kind of agency (Eisenhardt, 1989a; Emirbayer and Mische, 1998) to the process e.g. sense-making, strategic calculation, learning, making investments, conflict, power struggles, alliances, which makes transitions complicated processes that cannot be comprehensively addressed by single theories or disciplines.

In the archetypical transition narrative, transitions initiate when the sociotechnical regime is destabilised through niche innovations, internal regime tensions that can accumulate and create windows of opportunity for innovations in niches, landscape trends that put pressure on the focal regime (e.g. climate, economic, cultural, and demographic), and external influences or speciation from other systems, regimes, or niches (Papachristos et al., 2013). Change initiates in the periphery of the organizational field, where low regime structuration provides the conditions for niches where experimentation and learning about new technologies and related practices can take place (Geels, 2018; Geels et al., 2023a; Geels and Schot, 2007; Geels and Turnheim, 2022). If these peripheral niches succeed, then their momentum and structuration increase through accumulation and aggregation processes into increasingly larger niches which permeate increasingly institutionalized areas close to the organizational field core (Geels, 2002; Geels and Deuten, 2006; Geels and Schot, 2007; Schot and Geels, 2008).

Section 2.2 elaborates on speciation and aggregation drawing on transitions research, and then section 2.3 develops its counterpart drawing on PM research and concludes with a summary of key concepts in Table 1 that cut across the two literatures.

2.2. Speciation and aggregation from a transition perspective

The speciation and aggregation process involves four phases (Geels and Deuten, 2006; Geels and Johnson, 2018). In the first phase, new technologies are introduced through speciation from one application domain into another potentially followed by new firm entry (Astley, 1985; Adner et al., 2019; Levinthal, 1998; Cattani, 2006). This creative link of technology to a new application domain is a "quintessential entrepreneurial activity" (Levinthal, 1998, p 220), which consists in searching for new technologies and recognizing when a firm's technological knowledge base intersects with selection criteria of a new application domain (Adner et al., 2019; Cattani, 2006). The utilisation of such emergent instances requires strategic development efforts that require tremendous amounts of time and financial resources.

Speciation may involve little technology change, but the application of different technology selection criteria and differential resource availability in the new domain may trigger a divergent evolutionary path towards new technological form(s) (Levinthal, 1998), and a concomitant process of adaptation of technology and organizations (Leonard-Barton, 1988; Orlikowski, 1992). In the new domain, actor niche networks form around specific projects, locally applicable knowledge, and practices, and they experiment at the periphery of the organizational field away from the selection pressures of the dominant regime (Geels, 2018). For example, Corning, a US company founded in 1851, held long-standing expertise in specialty glass making, which it used to pioneer the first optical fibre for telecommunications in the late 1960s (Cattani, 2006). Between 1966 and 1970, Corning began to leverage its technological knowledge base in the development of fibre optics. It conducted the first laboratory experiments as it recognized its emerging opportunity and capitalized upon prior experience by forming a dedicated research team.

In the second phase, the *alignment* of actors in *networks* facilitates technology *knowledge exchange* in the new domain. *Learning* has an interorganizational but still local character, where the movement of actors helps overcome the stickiness of intra-organizational knowledge (Szulanski, 1996). The flow of actors also drives technology legitimation while professional societies and industry associations facilitate the accumulation and dissemination of technical knowledge. The interactions of firms involved in technology development i.e. producers, suppliers, users, and regulators, result over time in the accumulation and progressive *codification* and *institutionalization* of knowledge, cognitive rules and selection criteria that are shared among niche actors (Schot and Geels, 2008). This process increases the structuration of the niche (Fig. 1 vertical axis).

Returning to the example of Corning, it formed several partnerships in the early 1970s to circumvent AT&T's 80% monopoly of the US phone market at the time. Partnerships included Siemens in Germany, Pirelli in Italy, BICC in UK, public laboratories in France and Furukawa in Japan (Cattani, 2006). From these partnerships, Corning collected annual fees to fund its R&D efforts in fibre optics and acquired the complementary assets necessary to develop and defend its competitive position in those markets (Teece, 1986). During this period, Corning experimented with the new technology in pilot plants and conducted several field experiments to more fully understand the properties of the materials used in the production of fibres, perfect their quality, and lower production costs (Cattani, 2006). During this time, Corning sold mostly samples of fibres to telephone companies willing to test their potential.

In the third phase, knowledge production and circulation increase and acquire a global scope as actors and firms coalesce in *networks* around their common interests and intermediary actors perform dedicated knowledge activities at the global level to create, standardize, and distribute knowledge (Kivimaa et al., 2018). The *aggregation* and *structuration* of niche activities from the local to the global scope level involves the transformation of diverse local, context specific knowledge and selection criteria through standardization, codification, and formulation of best practices into robust, general, and abstract

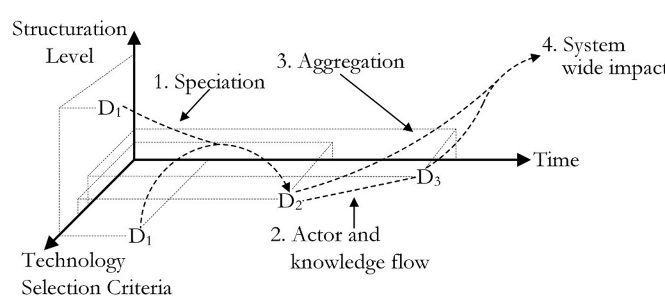


Fig. 1. Technology speciation in a new domain, niche aggregation and system wide impact (author interpretation of speciation and aggregation based on Levinthal (1998), Furr and Snow (2015) and Schot and Geels (2008)).

knowledge and cognitive rules that are no longer tied to a specific application context (Geels and Deuten, 2006; Raven and Geels, 2010). Knowledge transfer across projects is facilitated by institutionalization of knowledge sharing practices, and generalizable processes and norms.

Returning to the example of Corning, it codified its know-how in patents in early 1970s and defended them in two litigations for patent infringement. It licensed its patents and know-how to its partners outside the US to get them to commit to the new technology. However, these European joint ventures were only marginally profitable. The real breakthrough came in 1982 with the first long-distance telephone network that used single-mode optical fibres in the US, which challenged AT&T's dominance of the long-distance network market for the first time (Cattani, 2006). It led to the market wide adoption of single-mode fibres as a new standard. In parallel, the US government split AT&T in 1984 in eight firms which aided competition in the long-distance market and allowed entrepreneurial companies to challenge the existing technologies and embrace optical fibre to build new telecom networks.

In the fourth phase, local-level activities are shaped by the establishment of dominant cognitive rules and a global stock of knowledge, technology artefacts, and standards. Thus, the development of technology and associated selection criteria proceeds simultaneously at the local and global levels (Geels and Deuten, 2006; Schot and Geels, 2008). In this way, the *aggregation* process of several peripheral niches may produce generalizable knowledge through shared cognitive rules, structures and standards, which will permeate the organizational field core and bring about a transition (Geels, 2018; Raven and Geels, 2010; Schot and Geels, 2008). Standards are the most tangible and by definition codified outcomes of the *aggregation* process (Geels and Deuten, 2006; Geels and Raven, 2006). They enable complementarities between technological components, innovations, and sub-systems of technological architectures, and thus bind a socio-technical system together and contribute to its momentum, inertia, and trajectory (Manning and Sydow, 2011; Papachristos, 2017, 2020; Papachristos and van de Kaa, 2018; Papachristos and Van de Kaa, 2021; Van de Kaa et al., 2019). Returning to the example of Corning, the deregulation of the telecommunications industry by the US Telecommunications Act in 1996 further bolstered the use of fibre optics. More than 3000 new service providers began operating between 1997 and 2000 (Cattani, 2006). The Internet's rapid growth spawned new investment opportunities globally, such as server connections, and stimulated the search for additional advancements in optics-based technology.

Fig. 1 is a visualization of speciation and aggregation that can be used for further transitions theorizing (Langley and Ravasi, 2019; Swedberg, 2017; Weick, 1995b). The process starts with speciation of technology (1) from more or less developed/structured application domains (D_1) to a new application domain with different selection criteria (D_2). The evolutionary trajectory of technology in the new domain may diverge markedly from its antecedents due to the different set of available resources and the selection criteria that operate in the new domain (Astley, 1985; Levinthal, 1998; Adner et al., 2019; Cattani, 2006). Technology and knowledge flows that initiate in supplier-producer networks (2) and lead to knowledge accumulation and evolution of selection criteria (D_3) though it is still of a local character. The technology may remain specific to this niche or aggregate and reach other market niches, acquire a global dimension and increased level of structuration (3), and result in system wide impact and transition (4). The case-based version of Fig. 1 that illustrates the AEC trajectory is shown in Fig. 4.

2.3. Projects and organizational change

In this section we build a bridge to transitions research and the account of speciation and aggregation developed in section 2.2, by developing its counterpart drawing exclusively on PM research. Projects are temporary, time-limited networks and processes to which organizations commit resources for new capability development and the delivery of novel, complex outcomes while they manage the inherent uncertainty and need for capability integration (Cleland and King, 1983; Davies and Brady, 2000; Gann and Salter, 2000; Hobday, 1998, 2000; Hobday et al., 2005; Lundin and Söderholm, 1995; Sydow and Braun, 2018; Nisula et al., 2022; Turner and Müller, 2003). In the classical definition, projects are temporary endeavours designed to create a unique product, result, or service (PMI, 2021) involving a combination of people and other resources brought together in a temporary organization and process to achieve a specific goal (Davies, 2017).

PM is important as it represents an increasing share of organizational change initiatives and adaptation processes (Gareis, 2010; Gareis and Huemann, 2008; Lehtonen and Martinsuo, 2009; Lundin et al., 2015; Martinsuo and Hoverfält, 2018; Müller et al., 2016; Vuorinen and Martinsuo, 2018) and organizational life in general (Davies and Brady, 2000; Hobday, 2000; Keegan and Turner, 2002; Midler, 1995; Sydow et al., 2004; Turner, 1999; Whitley, 2006). Organizations engage increasingly in intra-organizational projects (Riis et al., 2019; Winch et al., 2012) or large interorganizational projects (Sydow and Braun, 2018; Szentes, 2018; Von Danwitz, 2018). In fact, the term projectification has been coined to reflect the organizational change from process to project-based decision making and the increasing reliance on management by projects (Davies and Brady, 2000; Gareis, 2010; Lundin et al., 2015; Midler, 1995; Müller et al., 2016).

Projectification involves the frequent shaping and reshaping of organizational structures owing to the temporary nature of projects (Bakker, 2010; Bakker et al., 2016), and thus PM is better suited to balancing organizational exploitation and exploration in dynamic environments (Biedenbach and Söderholm, 2008; Eisenhardt et al., 2010), as opposed to process management which tends to drive out experimentation in organizations (Benner and Tushman, 2003). The implication is that projects will be the likely mode of managing organizational change and adaptation for all firms in a particular organizational field during a transition.

2.4. Speciation and aggregation from a project management perspective

Organizations engage in project-based organizing and *learning* for adaptation and change in the face of inertia (Brown and Eisenhardt, 1995, 1997; Sydow et al., 2004; Sydow and Windeler, 2020). Through their transient and interdisciplinary nature, projects are suitable for innovation and new knowledge creation (Gann and Salter, 2000; Grabher, 2004; Hobday, 2000; Scarbrough et al., 2004a, 2004b). They serve as ad hoc milieus for knowledge recombination and the delivery of complex outcomes (Brady and Davies, 2004; Davies and Brady, 2000; Hobday, 2000; Iansiti and Clark, 1994; Lobo and Whyte, 2017; Lundin and Söderholm, 1995; Turner and Müller, 2003).

Opportunities for innovation and new knowledge creation arise in projects where the selection criteria for procurement require project partners to develop new capabilities (Brady and Davies, 2004; Davies and Brady, 2000; Prencipe and Tell, 2001). It follows that projects may be used to instigate discontinuous change through the introduction, recombination, integration, and application of current and new knowledge from disparate domains of application i.e. speciation (Levinthal, 1998) that enables organizations to adapt and/or probe into the future (Grabher, 2002; Iansiti, 1995; Iansiti and Clark, 1994; Manning and Sydow, 2011).

Nevertheless, organizations faced with uncertainty and risk also aim to balance exploration with exploitation by drawing on technologies and knowledge from past projects and combining them in novel ways (Brady and Davies, 2004; Davies and Brady, 2000; Kogut and Zander, 1992; Lavie and Rosenkopf, 2006; Lobo and Whyte, 2017). The use of this accumulated knowledge and procedures in a firm may give rise to capabilities and lessons that apply across similar, consecutive projects (Cooper et al., 2002; Williams, 2008). This drives aggregation and enables the use of project capabilities by firms for continuous, incremental change in repeat projects to reduce the uncertainty of project outcomes

(Atkinson et al., 2006; Nobeoka, 1995), and increase efficiency due to economies of repetition (Berggren, 2019; Brady and Davies, 2004; Davies and Brady, 2000; Lobo and Whyte, 2017), a development incipient in every recurring social pattern (Berger and Luckman, 1966).

It follows that organizations may initiate projects of an explorative nature to probe the future and adapt, and follow them up with projects that are exploitative in nature (Berggren, 2019; Brady and Davies, 2004). Contingent on the challenges organizations face, the mix of projects and their novelty may lie anywhere on a spectrum (Fig. 2) of exploration-exploitation (Davies and Hobday, 2005; Lundin and Söderholm, 1995; Randle and Pisano, 2021; Roehrich et al., 2024). For example, in exploratory projects knowledge introduced from different domains is recombined and integrated in new ways. Projects of this nature are more uncertain and ambiguous, and thus management has to attend more to project partner interpretations, *actor alignment*, and sense making (Louis, 1980; Weick, 1995a), particularly during preliminary design and planning activities (Thiry, 2002).

In this case, the degree and nature of stakeholder involvement and management of expectations will also differ in correspondence to the uncertainty and ambiguity surrounding the project aims and objectives (Thiry, 2002). Exploratory projects will also require different forms of performance evaluation that acknowledge the validity of different perspectives and worldviews and match the complexity of the project (Atkinson et al., 2006). In contrast, projects with low uncertainty and ambiguity warrant the collection of objective information to set precise targets and predictable processes in place, and their success is generally assessed with quantitative measures such as time and cost performance.

Organizational change usually lies in between discontinuous and continuous change (Brown and Eisenhardt, 1997; Gaba and Meyer, 2021; Hernes et al., 2021; Van de Ven, 2021; Weick and Quinn, 1999). It involves several stages and thus organizations in pursuit of adaptation and survival during a transition are likely to engage in a lineage of projects with an emphasis on knowledge exploration and capability recombination or speciation, for the delivery of complex, discontinuous outcomes, and projects with an emphasis on their exploitation, continuous improvement, and economies of repetition or *aggregation* (Berggren, 2019; Brady and Davies, 2004; Davies and Hobday, 2005; Eggers and Park, 2017; Kock and Gemünden, 2019; Maniak and Midler, 2014). The project lineage will facilitate organizational adaptation and change during a transition through the development of new organizational capabilities, the renewal of existing ones, and their repeated implementation over time (Andersen, 2006; Helfat and Peteraf, 2003; Helfat and Raubitschek, 2000; Zerjav et al., 2018), which will also result in concomitant changes in organizational structure (Clark, 1985; Colfer and Baldwin, 2016; Leo, 2020; McCormack et al., 2012; Tee et al., 2019).

Project partners form interorganizational networks to facilitate the *transfer* of complex knowledge (Powell, 1990; Uzzi, 1997; Zaheer et al., 1998). Their continuous involvement in a project lineage transforms their inter-organizational network into an aggregate project *network* organization with a past and prospective future (Lundin et al., 2015; Manning, 2017; Oliveira and Lumineau, 2017; Poppo et al., 2008; Sydow, 2021; Sydow and Braun, 2018). As time goes by, *structuration* in the project network increases with the accumulation of knowledge sharing and actor interactions who are associated with distinctive capabilities and knowledge, which facilitate activity coordination and makes actor behaviour predictable and stable (Berger and Luckman, 1966; March and Simon, 1958; Nelson and Winter 1982). Repeated collaboration across projects, establishes trust among partners and allows the development of project capabilities relevant for subsequent projects (Manning and Sydow, 2011; Sydow et al., 2004).

The capabilities and knowledge developed in a project lineage are *aggregated* and transferred to partner organizations through the *learning* processes that arise at the interface between a project network, its associated organizations, and the institutions in which it is embedded (Brady and Davies, 2004; Davies and Brady, 2000; Lobo and Whyte, 2017; Prencipe and Tell, 2001; Scarbrough et al., 2004a, 2004b). *Knowledge transfer* and *aggregation* relies often on connecting people through formal or informal networks (Koskinen et al., 2003; Williams, 2008), and so the transfer of knowledge across project networks is done through *empowering actors* and discussing practical problems, and constant realignment of project delivery requirements with firm related project capabilities (Bresnen and Marshall, 2001; Lobo and Whyte, 2017). Three key factors impact inter-project *learning*: organizational structures between projects, interproject assimilation practices, and actor alignment that facilitates the relationship with other projects (Lundin et al., 2015; Sense and Antoni, 2003). Learning is facilitated by *institutionalization* of knowledge sharing practices and delivery of materials, generalizable processes and norms, and the alignment and transfer of project members to new teams (Huber, 1991), to overcome problems in knowledge transfer within and across organizations (Szulanski, 1996).

The account of speciation and aggregation based on PM research in this section corresponds to the one in section 2.2 which is based in transitions research. To substantiate the bridge between transitions and PM research, Table 1 summarizes the key concepts highlighted in italics

Fig. 2. Spectrum of project characteristics based on Wheelwright and Clark (1992), Turner and Cochrane (1993), Olson et al. (1995), Lundin and Söderholm (1995), Shenhar (2001), Brady and Davies (2004), Atkinson et al. (2006), Thiry (2002), Lenfle and Loch (2010), and Roehrich et al. (2023, 2024).

Table 2
Literature used on the six projects in case study.

Project	Academic sources
Channel Tunnel	Arup (2004); Genus (1997); Pollalis and Georgoulias (2008); Pöttler (1992)
Heathrow Terminal 5	Arup (2006); Brady and Davies (2014); Caldwell et al. (2009); Davies et al. (2009); Davies et al. (2016); Gil (2009); Gil et al. (2012); Harty and Whyte (2010); Tee et al. (2019); Vedran et al. (2021); Whyte (2019)
London Olympics 2012	Brady and Davies (2014); Davies and Mackenzie (2014); Davies et al. (2014); Thiel and Grabher (2015); Vedran et al. (2021); Whyte (2019)
Crossrail	Arup (2012); DeBarro et al. (2015); Dodgson et al. (2015); Muruganandan et al. (2022); Pelton et al. (2017); Whyte (2019)
Thames Tideway	Gaunt (2017); Morgan (2020); Tideway (2021); Msulwa (2022)
High Speed Two	HS2(2019); Whyte (2019); Zerjav et al. (2021)

in sections 2.2 and 2.4 along with cursory references from transitions and PM research. In this way projects are established as a key middle range mechanism (Anderson et al., 2006; Davis and Marquis, 2005; Packendorff, 1995; Papachristos, 2018) through which organizational change may aggregate from one organization to the organizational field level. Considering speciation and aggregation from a PM perspective opens the additional possibility that speciation and aggregation led by incumbents, progresses from the organizational field core to its periphery rather than solely in the opposite direction as has been argued in transitions research (Berkhout et al., 2004; Geels, 2011). This is because large interorganizational projects or megaprojects are led by large incumbents who are at the core of the organizational field, because they occupy a central or hub position in their project network (Kenis and Knoke, 2002; Rowley, 1997). The implication is that innovations developed or adopted as ad hoc solutions through speciation in the delivery of project outcomes by incumbent actors at the core of the organizational field diffuse to actors in its periphery through project networks and aggregation (Abrahamson and Fombrun, 1994; Abrahamson and Rosenkopf, 1997). In this way, sociotechnical change associated with the innovation ripples outwards from the core to the periphery.

3. Research method and data

We investigate AEC digitalization with a longitudinal case study approach of six intertwined projects (Eisenhardt, 1989b; Yin, 1984). We selected them through theoretical sampling (Eisenhardt and Graebner, 2007; Pettigrew, 1990) because we consider them as central to AEC digitalization. In chronological order, the six projects are: (i) the Channel Tunnel Rail Link, (ii) Heathrow Terminal 5, (iii) London Olympics, (iv) Crossrail, (v) Thames Tideway and (vi) High Speed Two. Projects i-iv are completed, and projects v-vi are ongoing. Each project has been the subject of separate research which we draw upon (Table 2) and complement with industry reports, and in-depth interviews with eight industry experts, policy makers and practitioners which focus mostly on projects iv-vi. The interviewees were involved in all six project cases, and they were carefully selected to make up a diverse group in terms of age, gender and educational background. Additionally, the interviewees could be described as boundary spanners that enjoyed trust from various groups, because of the roles they occupied in the AEC industry during their career (Appendix A Table 1). Owing to their boundary spanning roles, they were able to offer different perspectives on projects, inter-project relations, and the AEC transition. Their input to our analysis increases the external validity of the research (Sarantakos, 2005).

The interviews lasted approximately an hour, structured with open ended questions on individual projects, their inter-relation and the overall AEC digitalization process. The interviews were coded to identify links between the six projects and establish the role of institutions, actors, and technologies. We coded interviews for key aggregation processes (Schot and Geels, 2008; Smith and Raven, 2012): learning, network development, and formation of actor expectations. We used jointly the literature in Table 2 and the interviews to construct an analytical narrative for each project that accommodates the data's richness and multi-dimensionality (Denzin and Lincoln, 2017). Emphasis was given to inter-organizational processes, particularly the bidirectional relation of projects, organizations, and industry level developments. The joint use of cases and interviews offer opportunities for complementary data gathering and analysis (Leonard-Barton, 1990). The analysis of completed projects documented in academic publications offers the opportunity to identify speciation and aggregation by induction as the overall AEC transition pattern while the study of ongoing cases and the interviews provide a close-up view on current project evolution and the mutual adaptation of technology and organizations in AEC (Leonard-Barton, 1988; Orlikowski, 1992).

The development of a narrative and a detailed story from raw data is a strategy for processual analysis, which affords a high degree of accuracy (Langley, 1999; Pettigrew, 1990; Weick, 1979), and thus works best with one or a few cases. We offer the cases as a specific instantiation of speciation and aggregation, but our aim is to treat it as a more general pattern in transitions research. Thus, we combine narratives and visual mapping as the strengths of each one counter the weaknesses of the other (Jick, 1979; Johnson et al., 2017; Miles and Huberman, 1994; Turner et al., 2015). For example, visual mapping allows the condensed presentation of information, and it is particularly attractive for process analysis as it can be used to show temporal precedence and parallel processes (Langley, 1999).

We use visual mapping to develop a speciation and aggregation pattern which is simple, condensed, but also general and thus of wider value to PM and transitions scholars (Golden-Biddle and Locke, 1993; Siggelkow, 2007; Tsoukas, 1989). Nevertheless, we do not claim this as a fully-fledged theory of speciation and aggregation for transitions studies as diagrams do not constitute theory development on their own, but are part of theory building blocks (Griffin, 1993; Sutton and Staw, 1995), and theorization (Langley and Ravasi, 2019; Swedberg, 2017; Weick, 1995b). In sections 4.1-6, we present a condensed vignette for each project followed by visualization in Fig. 4.

4. Results

The early origins of project management and computer aided design and manufacturing (CAD/CAM) tools can be traced to the US defence, aerospace industry, MIT and NASA (Chasen, 1981; Elliott, 1989; Llewelyn, 1989; Morris, 2011, 2013). Foundational work for CAD/CAM between 1955 and 1959 took place at MIT under the guidance of D.T. Ross (Ross, 1960, 1978) and Ivan Sutherland who developed Sketchpad in 1963, the ancestor of modern computer-aided design (CAD) (Konstan, 2007). In the aerospace and automotive industries, the link of design through CAD/CAM to manufacture and assembly gave a powerful impetus to standards for system integration and network linking (Hobday et al., 2005; Llewelyn, 1989).

Speciation of these technologies to UK AEC industry initiated with the move of academics and computers from US to Cambridge University and the application of Sketchpad to ship design at Imperial College in the 1960s (Elliott, 1989).[3] Speciation of computer technology begun when the British developed EDSAC computers were replaced by US developed TITAN in 1964/1965. TITAN was the first computer in Cambridge to support high-level languages, such as Fortran. Among the key actors was Professor Maurice Wilkes who, while visiting MIT, recruited Charles Lang, a computer scientist and mechanical engineer, to return to the UK, with support from Science Research Council (later EPSRC), and join him at the Cambridge University Computer laboratory. Professor Stanley Gill had also obtained joint support from the Science Research Council and the UK Ministry of technology to build a CAD team at Imperial College to research the computer processing of 3D shapes and the application of Sketchpad to ship design.

Political support and resources were mobilised in 1966, when the UK Ministry of technology considered a coordinated programme of CAD work at the National Engineering Laboratory, UK Atomic Energy Authority, Cambridge University, and Imperial College using US imported computers. This was envisioned as a £10million programme spread over 5 years aiming to make CAD self-sustaining by the end of that time. A CAD centre and the CAD Advisory Committee were established in 1967. The main priority was to assist UK firms to install, evaluate, and report on the use of available US CAD systems. Computers were initially adopted in aircraft and powerplant design and manufacture and eventually diffused to several industries including AEC where they provided the basis of a new approach to model civil engineering systems. Many standard packages around today trace their origin to the US space programme (Pipes, 1982).

CAD and building information management (BIM) software is considered as essential in AEC industry to meet its coordination and communication challenges in building design and delivery (Egan, 1998; Harty and Whyte, 2010; Latham, 1994), and reduce the performance gap between the design and actual building performance (De Wilde, 2014; Shrubsole et al., 2018). The coordination challenges are magnified in megaprojects, as each one has its own internal economy, governance structure, and production system (Davies et al., 2009). These challenges require collective organizational action to overcome resistance and adapt to new ways of work (Davies et al., 2009).

BIM has been widely acknowledged as ushering in a new paradigm in the AEC industry, expected to produce a range of benefits and transform the industry (Eastman, 1999). It is the result of efforts by industry consortia, such as BuildingSMART to standardize building information (East and Smith, 2016). BIM is not a standalone technology like CAD, because it cuts across traditional disciplines and supply chain boundaries and requires changes to project system integration (Hobday et al., 2005). BIM adoption is disruptive requires adaptation of technology at the organizational level and concomitant changes in the structure and practices at the organizational field and institutional levels (Morgan, 2019; Poirier et al., 2015).

4.1. Channel Tunnel (CT) (1985–1994)

The UK AEC in the mid-80s was characterised by inefficiency and low digitization. The discourse on improvements included visions of partnering, supply chain management, and lean manufacturing philosophy, ideas which were imported from other sectors, such as manufacturing (Bresnen and Marshall, 2001; Pavitt, 1984). At the time, the method to produce and share design information was through 2D plans (Harty and Whyte, 2010). In this context, CT was seen as a key infrastructure project for change in UK AEC sector. A consortium of industry incumbents consisting of Bechtel, Arup, Systra, and Halcrow was established to run the $10.3billion Channel Tunnel Rail Link project linking UK to Europe's high-speed rail network (Davies et al., 2009).

The technical complexity of CT pushed the technology boundaries in AEC. Digital innovations introduced from the US were a radical departure from prior established ways of working (Genus, 1997). They were developed to exchange building information through CAD applications, create a virtual building design prior to work on-site (Harty, 2005), and limit error-prone human interventions (Eastman, 1999). Technologies tested in CT included 3D modelling tools and other computer-based tools to deal with interoperability issues among different systems, such as project planning, cost management, procurement systems, and for facility management after construction.

In contrast to 2D plans that can be used and adjusted on-site, the implementation of 3D CAD in CT required broader organizational adaptations and support across the network of project partners. Full design specification was necessary to construct the virtual building, rather than provide partial 2D schematics which are fleshed out as on-site construction progresses, reconfiguring the sequences in which construction work is undertaken. The physical building had to match the virtual model exactly, and this constrained the activities of on-site workers and left no margins for changes. The implementation of 3D CAD thus, required organizational adaptations far beyond its location in drafting departments, as its repercussions reverberated throughout the inter-organizational network of construction work. This development informed the Latham (1994) and Egan (1998) reports that called for increased supply chain integration and collaboration and digital technology use to improve industry performance. Innovations used in CT paved the way for two subsequent CT phases in 2003 and 2007 (Arup, 2004; Pollalis and Georgoulias, 2008).

4.2. Heathrow Terminal 5 (T5) (1999–2008)

T5 was a US$8.5 billion project to increase the annual capacity of Heathrow airport from 67 million to 95 million passengers. T5 became a program of industry-wide change in the UK due to its size (Davies et al., 2009). Sir John Egan, author of the Egan Report (1998) and CEO of British Airports Authority (BAA) in the 1990s, used lessons from other major projects and industries to develop a novel delivery model based on a risk-bearing client, integrated project teams, and advanced construction techniques (Brady and Davies, 2014; Davies et al., 2009). In preparation for T5, Egan oversaw the development of a very strong internal capability in project management (Brady and Davies, 2014). Building construction in T5 was led by Terry Hill, chairman of Arup group (2004–2009) who had also led the CT proposal.

In the lead up to T5, BAA improved the delivery of its program of capital projects to modernize and upgrade its terminal buildings and airport infrastructure (Tee et al., 2019). BAA in consultation with T5 partners, committed to 3D CAD implementation to substitute traditional drafting practices, and coordinate design, construction, and information management across the whole project (Brady and Davies, 2014; Harty, 2005). This approach was enabled by inter-compatible design and drafting software packages and facilitated by a document management database. The vision of 3D CAD use at T5 relied on collaboration and information sharing across the whole project (Harty, 2005). In order to deliver to this end, T5 project managers drew on their knowledge and experience from past projects and from Heathrow terminal 4 project (Harty, 2005), and personnel transfer from CT to T5 to facilitate the further development of digital technologies (Tee et al., 2019). By exploiting the learning curve advantages and economies of repetition, BAA was able to achieve significant cost reductions in project delivery (Brady and Davies, 2014).

Building Information Management (BIM) was a systemic innovation at T5, as its consequences spread across partners (Harty, 2005). BIM was used to create a single-model environment (SME) and improve coordination, systems integration, and information flow of the construction process across partners (Davies et al., 2009; Tee et al., 2019). SME

[3] The online site of the physics department in Cambridge provides details on the computers that were installed throughout the 1970s and 1980s (https://www.tcm.phy.cam.ac.uk/about/history/computing.html accessed 26/12/2022).

hinged on the idea that if the project was built virtually first, problems could be identified prior to work on-site where errors are costly. In parallel to improved coordination in the construction process, BIM was seen as a way to eliminate the need for paper printouts, cardboard models, and thus reduce costs further.

The benefits of BIM were enough to convince project engineers and draftsmen to change their practices but were not enough to drive technology implementation at the organizational level. Considerable work was necessary to organise a coherent system of technologies and align them to the diverse expectations and practices of project partners (Harty, 2005). Negotiations between them indicated that software changes were necessary to align the BAA vision and the visions of services engineers and drafters. Software had to evolve from being primarily a design tool for 3D design to a manufacturing and control tool. T5 project activities thus, shaped software package functionality and triggered a cycle of mutual technology and organizational coevolution (Leonard-Barton, 1988; Morgan, 2019; Orlikowski, 1992; Tee et al., 2019).

The shift towards a digitalized process was not just a simple case of technology substitution but of fundamental changes in the organizational practices it facilitated (Harty, 2005; Harty and Whyte, 2010; Tee et al., 2019). The existing configurations in T5 were robust, so the more change initiatives challenged established practices and ways of work, the more they were resisted. Eventually, the digital link between design and fabrication was dropped and instead T5 engineers iterated between physical and digital models to fulfil tasks (Harty and Whyte, 2010). Knowledge on the radically new delivery model used at T5 influenced subsequent projects, including the London Olympics and Crossrail (Brady and Davies, 2014; Davies and Mackenzie, 2014).

4.3. London Olympics 2012 (2005–2012)

London Olympics transformed Stratford in east London, into a 2.5 km^2 Olympic Park with an athletics stadium, aquatics centre and velodrome with a budget of £8.1 billion (Brady and Davies, 2014). The London Olympics project (LO) drew on the lessons of T5 with digital technologies and software tools used for coordination at each phase of system integration, project design and documentation management (Davies et al., 2009; Davies and Mackenzie, 2014). At the same time, systems integration related to collaborative teamwork and managing uncertainty by mutual adjustment and collection of new information. In the 2012 Olympics, systems integration included digital ways of working, with information systems integration across the project. In the project, digital technologies and software tools were used as coordination devices at each phase of system integration (Davies and Mackenzie, 2014). Various digital systems were used for project documentation management, e.g. ProjectWise, where they pooled information about digital design of assets.

The leadership of John Armitt, author of the Armitt Review (2013), was crucial in the case of the Olympics Construction Programme. He oversaw the decision to employ an experienced and well-resourced delivery partner, the implementation of supportive contractual arrangements, and a program-wide culture of collaboration and a 'can-do attitude.' (Brady and Davies, 2014). The Armitt Review (2013) on UK infrastructure planning documented how the transfer of innovation from megaprojects, such as CT and T5, contributed to the successful delivery of the London 2012 Olympics construction program and the ongoing Crossrail project (Davies et al., 2014). The implications of the project extended beyond its scope and delivered assets, and left a learning legacy in participant organizations.

4.4. Crossrail (2008–2021)

Crossrail is a project of £14.8 billion (Davies et al., 2014), that will provide high-frequency suburban passenger service crossing London from west to east, it will increase London's rail-based capacity by 10% and will be used by approximately 200 million passengers a year. Crossrail is the first megaproject to introduce a formal innovation strategy (Worsnop et al., 2016), and the basis for several digital innovations in the AEC industry (Arup, 2012). Crossrail started with 2D deliverables, but it was completed in BIM and 3D digital deliverables. It was among the first UK projects to become PAS1192-compliant and use BIM as a digital platform for other innovations, such as laser scanning and augmented reality.

Crossrail was envisioned as an opportunity to promote innovation drawing on lessons learned from T5 and LO and transfer them to TT and HS2 (Pelton et al., 2017; Worsnop et al., 2016). In the lead up to Crossrail, a systematic search was done for innovative practices, products, and processes developed and utilized on other megaprojects—such as Heathrow Express, CT, T5, the Jubilee Line extension, and London Olympics (Davies et al., 2014). Several senior managers from London Olympics transferred their experience and innovative ideas on digital innovation to Crossrail, including Andrew Wolstenholme[4] Crossrail CEO and former programme director at T5. Wolstenholme wanted Crossrail to adopt advanced technologies such as compensation grouting, originally developed on the Jubilee Line extension, and BIM to provide a digital representation of the infrastructure asset throughout its life cycle (Davies et al., 2014; Dodgson et al., 2015).

In 2011, a collaborative innovation repository was set up by the Crossrail Innovation Team in association with Imperial College to provide a forum for partners and suppliers to contribute innovative ideas into the program, and implement them (DeBarro et al., 2015; Pelton et al., 2017; Worsnop et al., 2016). By October 2014, the innovation program had completed three evaluation rounds of over 700 innovation ideas and supported the development of 102 innovations (Dodgson et al., 2015). A BIM Academy was established in partnership with Bentley Systems to train all Crossrail subcontractors (Whyte, 2019). The Academy is also intended to help contractors use the knowledge and skill gained in other projects such as HS2 and TT, promote digital innovation in the industry in support of the Government Construction Strategy (GCS), increase BIM use and create a lasting legacy of best practices in the industry. Sharing Crossrail innovations with other megaprojects was championed by its senior management team who aimed to contribute something to future projects in much the same way previous projects had invested in sharing their innovations (e.g. organizational structures) with Crossrail (Davies et al., 2014). Many senior managers from LO and Crossrail went on to other projects e.g. Mark Thurston CEO in HS2.

4.5. Thames Tideway (TT) (2012–2023)

TT is a £4.2 billion project to manage sewage and rainwater that currently overflows into Thames River (Msulwa, 2022). TT is the first project where all partners adhere to BIM Level 2 for digital model-based delivery (Gaunt, 2017). The transfer of experience from Crossrail was instrumental in this, and was enabled by Andy Mitchell TT CEO, programme director and board member at Crossrail, and Andy Alder programme delivery director at TT and project manager for construction at Crossrail.

Significant efforts were made during initial procurement to assess and mitigate the risks of BIM delivery. While contractors were required to use BIM, the TT team adopted a 'technology agnostic' approach during tendering to reduce risk. The reason was prior experience from projects including Crossrail where the choice of a particular software transferred the risk to the client. The TT team defined project deliverables from a digital blueprint and the BIM Execution Plan but encouraged contractors to use tools they already had expertise in so that they

[4] Prior to joining Crossrail, Wolstenholme was Director for Innovation and Strategic Capability at Balfour Beaty, a company involved in Thames Tideway and High Speed 2.

would transfer experience back to their organizations. The TT team is also heavily involved in the Infrastructure Client Group to promote digitalization in AEC and align with broader infrastructure digitalization. The aim is to draw on the lessons of the Crossrail and London Olympics, create a digital learning legacy, share best practices and pass on lessons to HS2. The diffusion of ideas from these projects is particularly evident in HS2 and Thames Tideway (Pelton et al., 2017).

4.6. High Speed two (HS2) (2017–2026)

HS2 is £51.8 billion project[5] for a major high-speed rail line to link London, Birmingham, Manchester, and Leeds. The direct involvement of senior management staff from previous projects i.e. London Olympics, Crossrail, and HS2 enables the collection and utilisation of knowledge to go a step further and construct the digital twin of the physical asset. HS2 is one of many industry initiatives that contribute to the vision of Digital Built Britain. In this regard the HS2 team works closely with government departments, with major infrastructure programmes, and professional institutions to develop standards and requirements that are reasonable for the supply chain, and introduce solutions that will benefit the entire industry and create lasting change such as its BIM upskilling platform (HS2, 2019).

The legacy of HS2 in the AEC industry includes raising awareness that BIM is a core competence which firms must develop. It necessitates a data management perspective, and further development of standards like ISO19650 for BIM adoption. Among the ambitions of the Infrastructure Client Group (ICG) is to establish standards that all ICG members will sign up to and enforce across all of their projects. Collaborative efforts are seen as key to overcome setbacks, for example the involvement of partners from all project stages at the front end of the project. In this respect more governmental initiatives are seen as a necessary follow up on the 2011 UK BIM mandate. 2016 marked a turning point with less government involvement but industry sentiment was that government support and top-down leadership, was still necessary.

4.7. Aggregation through institutional and organizational developments

In parallel to the six projects, the UK government promoted digitalization of AEC through three initiatives, the Avanti Programme, the BIM Agenda, and Digital Built Britain. The Avanti programme in 2001, was one of the first institutional initiatives to explore collaborative digital working (Bew and Richards, 2008; Morgan, 2017). It was a collaboration of the Department of Trade and Industry with incumbent UK AEC firms, universities, and R&D organizations. The initiative underlined the significant challenge and need to develop the essential practices for collaboration with digital technologies such as BIM. Avanti laid the groundwork for BIM British Standard BS1192 and had an equally important influence on changing the organizational culture in AEC from adversarial to collaborative. In 2006, the Avanti brand ownership was transferred to Constructing Excellence (CE), an industry body that was formed as the aggregator of several other industry bodies to implement the improvement agenda laid out in the Latham and Egan Reports.

With the BIM Agenda, the UK government led the development of new processes for digital delivery (Whyte, 2019). In 2011, the introduction of the UK Government Construction Strategy (GCS) was a milestone development which mandated that selection criteria for government procurement on all public sector projects after April 2016, would require a minimum of BIM level 2 compliance, fully collaborative 3D BIM with delivery of digital project and asset information, documentation, and data. After the announcement of GCS in 2011, the British Standards Institute issued the suite of Publicly Available Specifications (PAS) 1192. In 2011, the UK government created and funded the BIM task group to support the BIM level 2 mandate, and further develop its criteria. The initiative changed project delivery models by altering incentive structures, procurement methods, stage-gates in the process, common standards for using digital information, client communication.

In 2016, the Cabinet Office and the Infrastructure and Projects Authority (IPA) issued the 2016–2020 GCS which emphasized the reliance on infrastructure megaprojects to digitally transform the AEC sector and underlined BIM and Digital Construction as important elements in increasing productivity and collaboration (Office, 2016). After the dissolution of the BIM level 2 task group, some of its members formed the UK BIM Alliance, to provide leadership and continue efforts with information exchange and deliberations for increased BIM standardization, adoption, and implementation. The BIM 2 Group was succeeded by a task group to work on the BIM Level 3 mandate as part of the Digital Built Britain strategy (Whyte, 2019). BIM Level 3 requires extensive changes in procurement, and collaborative use of digital information.

These government initiatives and standards enabled the diffusion of BIM, but it was also supported by organizational leadership, employee training and skills development (Morgan, 2019). BIM implementation impacts on all the processes within the project organization and the product life cycle of project deliverables; therefore, it is not a standalone software tool but rather a process to be managed systemically (Eadie et al., 2013; Whyte et al., 2016). Its adoption and implementation necessitate other digital innovations across project networks in AEC, in terms of organization, governance, and service diversification. BIM requires rather than creates greater firm collaboration for successful implementation (Harty, 2005), as shown by research on how BIM adoption needs to be brought together in contracting, SME, engineering, and design firms (Morgan, 2019; Poirier et al., 2015; Shibeika and Harty, 2015). The design firm and the early project design stages are the starting point for the adoption and use of digital technologies and innovation waves that can eventually ripple across the entire AEC project network (Boland et al., 2007; Sebastian, 2011).

In summary, each one of the projects in our analysis involved a combination of top-down government procurement and standard setting initiatives (Fig. 3), and bottom-up opportunities for innovation in projects and aggregation at the organizational field level driven by technology adoption and organizational adaptation (Winch, 1998; Wolstenholme et al., 2009). The digitalization process of the AEC industry involved changes at the institutional and organizational levels which required changes beyond the IT department of firms (Morgan, 2019; Poirier et al., 2015; Sergeeva and Winch, 2020; Winch, 1998). Government procurement initiated projects with the ambition to deliver

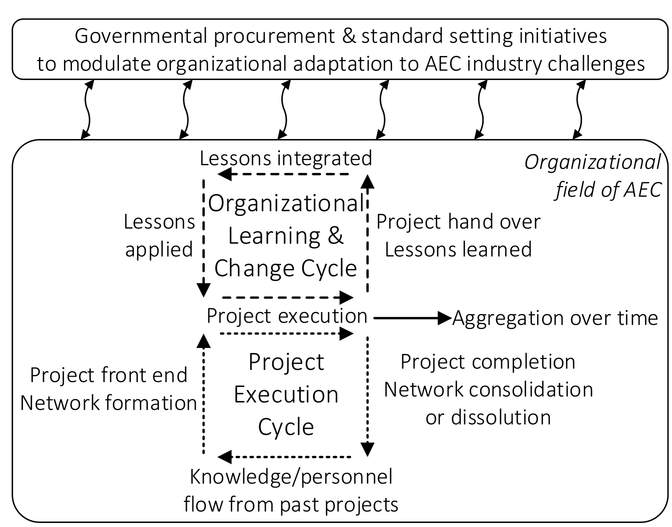


Fig. 3. Top down and bottom-up dynamics influencing industry developments over time based on Thiry (2002), Pellegrinelli (1997), Ring and Van de Ven (1994) and the EFQM model (2021).

[5] Figure quoted in https://www.hs2.org.uk/.

impactful outcomes, which presented the AEC industry with a set of challenges. Project networks led by industry incumbents and leading practitioners were involved in shaping the AEC industry consensus documented on several reports on how it should move forward to meet the challenges. This consensus provided the impetus and direction for change across all major industry stakeholders.

Essential learning processes arose during the *project execution cycle* (Fig. 3) at the interface between the associated organizations, networks, and institutions in which they were embedded (Prencipe and Tell, 2001; Scarbrough et al., 2004a, 2004b). Project partners drew upon their knowledge and relevant experience from prior projects, and after each project they consolidated experiences and lessons learned which provided the input for the institutionalization and update of industry standards for digital technologies use. Upon the completion of each project, part of the stakeholder network was consolidated and engaged in subsequent projects. This created the opportunity and space for the transfer of senior managers, knowledge, and lessons learned across projects and organizations which drove the *organizational learning and change cycle* through which the organizational change of incumbents extended to their subcontractors in the AEC network. The operation of the two cycles in tandem gave the aggregation process momentum which along with mechanisms of isomorphism (Miterev et al., 2017) made organizational change of incumbents ripple outward from the organizational field core to its periphery.

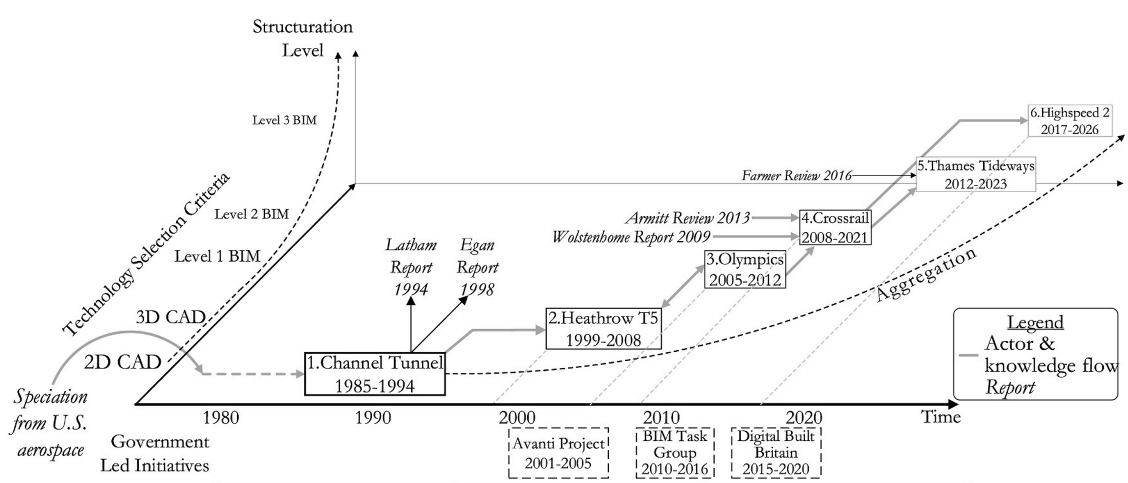
4.8. The trajectory of AEC digitalization from organizational field core to its periphery

The trajectory of speciation and aggregation of the digitalization process of UK AEC evolved and changed with each megaproject. The process is illustrated in Fig. 4, which is an instantiation of the stylised pattern of speciation and aggregation in Fig. 1 informed by the account of UK AEC developed in section 4. Fig. 4 illustrates the AEC trajectory along three axes of time, structuration level, and change in technology selection criteria (BIM Levels). Boxes represent key events such as projects and government initiatives industry reports are included in italics, grey arrows indicate the sequence of the events, and flow of personnel and knowledge over time.

In this way Fig. 4 accomplishes three aims. First, it illustrates AEC digitalization as a process over time (x-axis) of speciation and aggregation visualised in Fig. 1. Second, it traces the evolution in *technology selection criteria* (z-axis). It is shaped by policy, industry reports, and the agency of scholars and practitioners for the adoption of BIM (Dainty et al., 2017; Morgan, 2017). It also traces the increase in structuration levels (y-axis) which is driven by the flow of knowledge and key personnel between projects that result in the development and establishment of project rules across the AEC industry. For example, the structuration level of activities in the AEC organizational field has risen considerably with the 2011 mandate for the use of Level 2 BIM compliance for government procurement on all public sector projects after April 2016 and the Digital Built Britain strategy towards Level 3 BIM (Whyte, 2019). Third, Fig. 4 juxtaposes the AEC trajectory along with a summary of concurrent developments in three key dimensions that are standard part of sociotechnical analyses (Geels, 2004): (i) rules and institutions, (ii) actors and social groups, and (iii) digital technology evolution.

The UK government has mandated BIM use from 2016 on all public sector projects, which account for 40% of all construction work (Morgan, 2019; Sergeeva and Winch, 2020). These large projects are ideal places for BIM application and innovation for given their large number of participants (Davies et al., 2014; DeBarro et al., 2015).

The rationale is that large AEC incumbents will invest in BIM to comply with specifications of government procured projects given the size of the public sector. This will drive BIM diffusion in AEC, and subsequently the co-adaptation of technology and organizational changes will permeate their entire project network (Boland et al., 2007; Sebastian, 2011). The underlying assumption in UK policy is that digital technology will deliver a range of benefits for all firms and at all project scales (Eastman et al., 2011; Sebastian, 2011). Such innovations are expected to have industry-wide impacts beyond in-project performance



Rules & Institutions	Limited institutional change from government sponsored industry reports calling for change No rules developed	Institutional change by sponsoring an institutional and collaborative project Project outputs become basis of British Standards Government Construction Strategy 2011	Substantial institutional involvement via new technology mandates in public procurement Issuing of standards to lead change BIM PAS1192-5 Publication 2013 Construction 2025 Report Publication 2013
Actors & Social Groups	Firms become sporadically aware of the need for change No new entrants	Incumbents reorient incrementally by adjusting their processes New government-sponsored groups & communities emerge to drive change	Incumbent firms reorient substantially, to new technology and business model New alliances between incumbents and new entrants
Digital Technologies	The need for technological change is accentuated in complex projects Digital tools complement and substitute existing ones	Incremental progress in existing technologies Incorporation of symbiotic innovations & add-ons that change the processes	From initial add-ons to new hybrids of new and existing technologies Partial or full technical substitution of tools that brings new processes

Fig. 4. Timeline of UK megaprojects and evolution in digital innovation criteria in UK AEC.

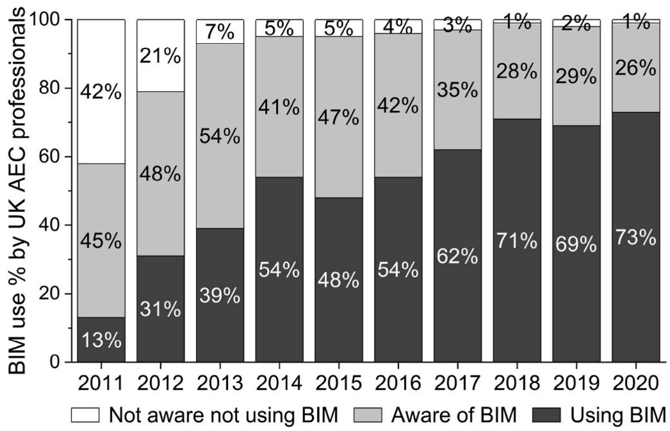


Fig. 5. Share of UK AEC professionals using BIM, adapted from NBS (2020).

improvements (Worsnop et al., 2016). They will bring about changes in the organizational field, client demands and technology advances that will require firms to manage and develop their capabilities for digital project delivery (Shibeika and Harty, 2015).

This rationale seems to have worked as BIM adoption has gained momentum in the UK (Fig. 5), driven by large incumbents (Shibeika and Harty, 2015), who developed strategies and capabilities they can use across projects (Worsnop et al., 2016). However, BIM compliance requires considerable resources, so it is likely to be particularly problematic for small firms which do not have the resources or capacity to invest in technology adoption, training, and application. Indeed, BIM adoption is lower among SMEs that make up 90% of UK AEC firms (Ayinla and Adamu, 2018). Higher BIM maturity levels will be difficult to achieve for small firms in the future largely because of the increasing sophistication of BIM technologies and the associated financial commitments required to operate successfully. Thus, the digitalization progresses from the organizational field core but is unlikely to reach the full extent of its periphery resulting in a digital divide between organizations that readily access and use ICT and those that do not (Ayinla and Adamu, 2018).

5. Discussion

This study views large projects as places where incumbent actors engage in joint endeavours of technology standardization with the government. Technology speciation from US defence and aerospace industry to UK AEC triggers the digitalization process in which the six projects provide the locus for implementation and adaptation of digital technology by industry incumbents (for an illustrative list see Appendix A, Table 2), the refinement of BIM selection criteria and standards, and the development of new regulations. The flow of key management personnel across projects and institutions and their boundary-spanning capabilities drives digital innovation and standardization (Levina and Vaast, 2005). The standardization and aggregation trajectory is punctuated by the Egan Report (1998), the 2011 UK BIM mandate for digital project delivery and the evolution of BIM selection criteria for public procurement.

Changes at the organizational and institutional levels influence mutually constitutive relations between institutions, organizations, the adoption of digital technologies and the way their alignment enables digitalization (Morgan, 2019; Shibeika and Harty, 2015). The adoption and implementation of BIM at the project level requires new forms of collaboration between firms (Harty, 2005) which inevitably trigger organizational changes (Leonard-Barton, 1988; Morgan, 2019; Orlikowski, 1992). They span design, construction and post commission work and eventually ripple across the entire AEC organizational field from its core to its periphery (Boland et al., 2007; Harty, 2005). This is due to the resources and industry position of incumbents that enables them to adapt to institutional developments and impose their preferred standards to their 1st and 2nd tier suppliers.

5.1. Relating to transitions literature

The discussion of the AEC case cannot account for the multiplicity of all the groups involved in the AEC industry and the complete range of developments relevant for the trajectory of the industry. Nevertheless, the case shows how early consensus, direction-setting, and sustained resource commitments enable institutional entrepreneurship by incumbent industry firms, actors (Battilana et al., 2009), and drive speciation and aggregation. The strategic consensus on the vision for the AEC industry is exemplified in industry reports (Armitt, 2013; Egan, 1998; Farmer, 2016; Latham, 1994; Wolstenholme et al., 2009). The lineage of projects drives the digitalization process of the AEC industry. They facilitate the development and application of technology selection criteria for public procurement (BIM levels) and the aggregation of knowledge which is then carried over in successive projects. The purposeful character and focus of industry change efforts indicates that each megaproject can be considered as a niche for analysis purposes (Papadonikolaki et al., 2023).

Incumbents in the AEC industry led the projects and the digitalization process so it could also be argued that it had a competence enhancing rather than competence destroying character (Bergek et al., 2013; Christensen and Rosenbloom, 1995).[6] In this respect, the digitalization process concerns innovations that are symbiotic to the UK construction system, so it bears some similarity to the reconfiguration pathway (Geels and Schot, 2007). Digital technologies are initially adopted as an add-on to cope with challenges in the Channel Tunnel project and trigger further technology development and adoption and organizational adaptation. The case also resembles a transformation pathway as the basic architecture of the regime remains the same (Geels and Schot, 2007).

Nevertheless, the digitalization case deviates from the archetypical transition narrative where new entrants and outsiders challenge dominant incumbent actors and regimes. The focus on the use of technology in projects from the start of the digitalization process is in stark contrast to the diverse niche visions, open-ended experimentation, stakeholder expectations and technology development processes that converge and present an alternative to the dominant regime, and diffuse through market adoption processes (Kemp et al., 1998; Schot and Geels, 2008; Smith and Raven, 2012; Turnheim and Geels, 2019). In contrast to the literature, the digitalization process seems to open divergent technology possibilities. Digital technologies open multiple possibilities in projects e.g. advanced applications of BIM, additive manufacturing, 3D printing, big data analytics, artificial intelligence, and blockchain technology (Steen et al., 2022).

The case introduces projects as middle range mechanisms (Anderson et al., 2006; Davis and Marquis, 2005; Packendorff, 1995; Papachristos, 2018) of speciation and aggregation in transition processes that can potentially establish multi system interactions as well (Papachristos et al., 2013). It illustrates that speciation and niche aggregation may initiate anywhere in the core-periphery architecture and hierarchy of the organizational field and shape transition dynamics. The role of AEC incumbents in catalysing change rather than raising barriers to it suggests that scholars should consider aggregation processes that proceed from the level of local niches to global regime and from the periphery of the organizational field to its core but also its counterpart i.e. change that proceed from core to periphery and global to local levels which may include the strategic reorientation of incumbent actors through dynamic

[6] The authors would like to thank Frank Geels for raising this point.

capabilities in relation to technological or other environmental influences (Bergek et al., 2013; Eggers and Kaplan, 2013; Turnheim and Geels, 2013, 2019; Zollo and Winter 2002). Indeed, studies of institutional change point to change being initiated by high-status organizations (Greenwood and Suddaby, 2006; Greenwood et al., 2002; Sherer and Lee, 2002), which are said to be at the centre of an organizational field (Shils, 1975).

We expect that the insights developed in this paper apply more broadly to all industries owing to the ubiquity of projects in modern organizations and economies[7] (Lundin et al., 2015; Midler, 1995; Roehrich et al., 2024), and thus by extension we expect that PM is broadly relevant for transitions research. The digital transformation in AEC is part of a ubiquitous process of digitalization and thus, it bears similarities to other sectors where the digital representation of information enables analysis and algorithmic manipulation (Adner et al., 2019; Andersen et al., 2021; Correani et al., 2020; Iansiti and Lakhani, 2014; Lanzolla et al., 2020, 2021; Warner and Wäger, 2019). For example, "digital twins" currently enable the digital representation, through simulation models, of physical processes such as the wear and tear of components or infrastructure. Digitization creates new connections and enhances existing connections among objects, individuals, and organizations (Siggelkow and Terwiesch, 2019). This transition to always-on connectedness enables revolutions in search, monitoring, and control (Adner et al., 2019). The adaptation of organizations to the forces of digital transformation is itself a topic of intense research interest (Furr and Shipilov, 2019).

5.2. *Theoretical bridge between transitions research and project management*

The interest and attention to the role of projects in transitions research is increasing as most of the efforts to decarbonize industry sectors take the form of large interorganizational projects or megaprojects lead by incumbents (Sovacool and Geels, 2021; Sovacool et al., 2022). It makes sense to explore at least four opportunities for bidirectional exchange between PM and transitions research. First, structuration theory provides the basis for exchange of insights on multi-level research and theoretical integration between transitions and PM (Geels, 2002, 2004; Geraldi and Söderlund, 2018; Sydow and Windeler, 2020; Windeler and Sydow, 2001). Structuration is understood in PM and transitions research as a dynamic process that is embedded historically in more permanent contexts (Fuenfschilling and Truffer, 2014; Sydow and Windeler, 2020). Organizational rules and resources are constituted, enable, and constrain temporary project organizing activities that are embedded in more permanent interorganizational networks and organizational fields which in turn constitute the context where projects are embedded (Manning, 2008; Sydow and Windeler, 2020).

Second, transitions research can draw on PM literature to go beyond theorizing experimental projects as elements of niches that are peripheral to the organizational field and consider large projects as niches too (Papadonikolaki et al., 2023). Incumbent firms that lead projects at the core of the organizational field have considerable leverage in setting requirements to their 1st and 2nd tier suppliers at the field periphery (Sherer and Lee, 2002), e.g., Arup, AECOM, Bechtel, Walmart, Amazon, and Apple. Thus, when incumbents like these act as institutional entrepreneurs to initiate change through projects, organizational change will ripple outward from the organizational field core to its periphery. Projects are thus a key middle range mechanism (Anderson et al., 2006; Davis and Marquis, 2005; Packendorff, 1995; Papachristos, 2018) through which organizational change led by incumbents aggregates from one organization to the project network, and to the organizational field level. In this respect it is worth reconsidering the reconfiguration and transformation MLP pathways (Geels and Schot, 2007), from a PM perspective.

Moreover, large projects are often of long duration spanning years or decades, which may give rise to interorganizational relations and learning processes similar to those that develop between permanent organizations that participate in niches. The implication is that organizational change and project success are best analysed in the context of a series of projects that organizations participate in, and broader institutional processes (Battilana et al., 2009; Biesenthal et al., 2018; Dille and Söderlund, 2011; Engwall, 2003; Powell and DiMaggio, 1991; Sense and Antoni, 2003). In these settings, there is an opportunity for the bidirectional exchange of insights on learning, knowledge transfer and aggregation between transition and PM research. The reason for this is that organizations that are likely to shape a transition the most, are those incumbents that survive it due to their size, past experience and complementary assets (Eggers and Park, 2017), i.e. firms like Microsoft, Apple, Intel, Google, and Toyota (Cusumano, 2010).

Third, taking an institutional perspective opens another bidirectional avenue between PM and transitions research (Lundin et al., 2015; Morris, 2011). The successful completion of large projects requires considerable institutional entrepreneurship and strong project ownership or sponsorship (Battilana et al., 2009; Biesenthal et al., 2018; Brady and Davies, 2014). Project management scholars advocate for more fine-grained analyses of projects in their institutional context (Dille and Söderlund, 2011; Engwall, 2003; Grabher, 2004; Kadefors, 1995; Morris and Geraldi, 2011). This also raises the issue of project timing in relation to a favourable or unfavourable institutional context (Dille and Söderlund, 2011), and coincides with recent calls to explore the role of large-scale technological options for low carbon transitions (Sovacool and Geels, 2021; Turnheim and Geels, 2019), and the importance of timing and sequence of projects and windows of opportunity transitions (Tongur and Engwall, 2017).

Fourth, interorganizational relations, governance, coordination, and actor alignment are important from a PM perspective but underdeveloped (Roehrich et al., 2023, 2024; Sydow and Braun, 2018). In this regard, the Multi-Level Perspective in transitions research (Geels, 2020; Geels and Schot, 2007; Papachristos et al., 2013) can be the starting point to address the calls for a similar perspective in PM research (Biesenthal et al., 2018; Biesenthal and Wilden, 2014; Geraldi et al., 2011). The research scope will need to extend beyond the individual project to the management of a project network (Sydow, 2021) and a project lineage, knowledge transfer from one project to another, to permanent organizations and the organizational field and institutional context in which they are embedded (Engwall, 2003; Windeler and Sydow, 2001). The analysis of inter-project transfer of knowledge could benefit from transitions research on how niche practices accumulate, aggregate, and change the organizational field, and, in turn, shape these practices (Geels and Deuten, 2006; Schot and Geels, 2008; Smith and Raven, 2012).

Similarly, transitions research on niches can draw on the vast PM literature on factors that inhibit knowledge development and transfer between projects (DeFillippi and Arthur, 1998; Gann and Salter, 2000; Keegan and Turner, 2001, 2002; Koskinen et al., 2003; Williams, 2008). This can highlight the role of projects for generating organizational inertia and path creation (Berggren, 2019; Garud and Karnoe, 2001; Sydow et al., 2009). There is probably as much to cover and discuss for the multiplicity of the groups and forms of project delivery, for local-global niche dynamics of learning, experimentation, and actor network formation that we did not cover in this paper. We acknowledge the limitation of our work in that the choice of specific projects excludes by default other relevant projects in UK AEC, and thus there is more to be said about the AEC digitalization. We hope that joint PM and transitions work will result on a more nuanced understanding of how this multiplicity of factors and actors is situated in a large project-based context and how that is influenced by other actors.

[7] We would like to thank one of the reviewers for raising this point.

5.3. The role of projects and project managers in shaping the institutional environment

The analysis of speciation and aggregation highlights the agency of senior managers (Eisenhardt, 1989a; Emirbayer and Mische, 1998) for example the influence of Wolstenholme and other senior executives and their knowledge brokerage role in successive projects (Burt, 2004). The role of senior managers in successive projects had an element of iteration informed by their past experience, which they brought to the present, while their actions were also oriented towards the future and the direction envisioned for the AEC industry. The consolidation and reuse of individual knowledge bases is what enabled work and knowledge integration in projects (Hobday et al., 2005; Sydow et al., 2004). Top management support was key to create a conducive environment to successful innovation in projects (Elenkov and Manev, 2005).

The case analysis highlights managers as key agents of alignment, change, and adaptation of organizational capabilities to challenges (Eggers and Kaplan, 2013; Elenkov and Manev, 2005; Winch, 1998). Managers perceive opportunities and respond to challenges that arise in the environment, so managerial cognition and interpretation plays a key role in capability reconfiguration for organizational adaptation (Kaplan, 2011; Kaplan and Tripsas, 2008; Lavie, 2006; Walsh, 1995). Thus, purposeful interpretation matters for overcoming organizational path dependency, instigating path creation through purposeful action (Emirbayer and Mische, 1998; Garud et al., 2010; Sydow et al., 2009), and reconfiguring organizational capabilities to match emergent opportunities in environment (Bingham et al., 2007; Gavetti and Levinthal, 2000; Zollo and Winter 2002).

In this respect, the involvement of senior managers like Wolstenholme in successive AEC projects was central to the digitalization process. Their experience and understanding of organizational capabilities increased the likelihood that they were redeployed to solve new problems (Felin et al., 2012; Gavetti, 2005; Helfat and Peteraf, 2014; Miner et al., 2011). They perceived the challenge that involved the adoption of digital technologies and the reconfiguration of the capabilities of AEC organizations (Cohen and Tripsas, 2018; Lavie, 2006). Owing to the AEC industry consensus documented in several reports, there was a degree of alignment and continuity of effort in the participation of senior managers in successive projects. Senior managers took the appropriate course of action to shape the strategic direction of incumbent participant firms and align them with government innovation narratives to secure participation in future projects (Sergeeva and Winch, 2020).

Overcoming resistance to change involved an institutional entrepreneurship spirit[8] and agency in institutional work and organizational change (Greenwood and Suddaby, 2006; Hampel et al., 2017; Lawrence and Suddaby, 2006). This generated endogenous technological opportunities, in addition to those of speciation. AEC incumbent firms had the capacity to engage in and support research and development that fed back into innovative activity and generated technological opportunities e.g. the establishment of BIM Academy and the more than 700 innovative ideas evaluated by the Crossrail Innovation Team. Incumbents adopted and adapted to these innovations in projects and thus initiated path creation away from past practices. At the same time, senior managers by enacting their strategies they compelled their subcontractors to overcome their path dependence as well thus they actively shaped the AEC organizational field (Bohnsack et al., 2021; Burgelman, 2002; Fortwengel and Keller, 2020; Gavetti et al., 2017; Hamel and Prahalad, 1989; Helfat, 2022; Rindova and Courtney, 2020; Suddaby et al., 2020).

The adoption of digital technologies and the reconfiguration of capabilities for path creation (Garud et al., 2010; Sydow et al., 2009) involved a degree of deliberate organizational learning and forgetting (Argote et al., 2021; Benkard, 2000; Crossan et al., 1999; De Holan and Phillips, 2004; Zollo and Winter 2002). These are constitutive processes of organizational change where social elements of organizations unravel and are reconstituted simultaneously with technical elements that become obsolete and are replaced. These processes are usually initiated by managers, take time, and thus involve organizations linking their past, present and future as they adapt during a transition (Berggren, 2019; Brown and Eisenhardt, 1997; Kock and Gemünden, 2019; Maniak and Midler, 2014). For example, in the AEC case, capabilities associated with the development of physical buildings models was discontinued as it was being replaced by digital technologies. This development started in AEC incumbents and its implications rippled outwards towards industry subcontractors effectively shaping the transition dynamics at the organizational field level.

6. Conclusions

The paper bridges PM and transitions research to understand how the inter-relationships among key infrastructure projects, institutions, and actors influence digital innovation. The bridge between PM and transitions research is instantiated in the case of AEC digitalization which is conceptualised as a combination of technology speciation and aggregation processes that unfold over several successive projects. The paper offers an understanding of projects as a middle range mechanism for speciation and aggregation in transitions research. The case analysis documents how the speciation of digital innovations to UK AEC industry and aggregation drives incumbent organizational change processes and shapes institutions, digital technology standards, and regulations. The movement of knowledge and key actors across projects catalyses the adoption of digital technologies and change at the core of the organizational field that ripples outwards to its periphery. We hope that our work will trigger joint PM and transitions work and result on a more nuanced understanding of project-based organizing in transitions and the factors that influence it.

CRediT authorship contribution statement

George Papachristos: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Eleni Papadonikolaki:** Methodology, Investigation. **Bethan Morgan:** Methodology, Investigation.

Data availability

No data was used for the research described in the article.

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[8] We would like to thank one of the reviewers for raising this point.

Appendix A

Table 1
Profiles and identifiers of the interviewees for external validation of the research

Interviewee Identifier	Current role	Professional Background	Position/Area of expertise	Institutional roles held currently or in the past
I_1	Chief Scientist at the Building Research Establishment (BRE) and Professor at Higher Education	Chartered Engineer and a Fellow of the Royal Academy of Engineering;	Significant policy and industry expertise	Chief Scientific Advisor for the Department of Communities & Local Government. Chair of BuildingSMART UK, Past President of the Institute of Engineering and technology
I_2	BIM Strategy Manager at HS2	Computer Scientist and Chartered Project Manager	BIM Strategy Manager at High Speed 2 (HS2)	BIM Consultant at Transport for London (TfL)
I_3	Digital Built Britain (BIM) Advisor at a software provider	Design Engineer	Manager of the Crossrail BIM Advancement Academy	Chair of the Asset Data Dictionary in the UK. Member of the UK BIM Task Group
I_4	Research Associate in Construction Law group in Higher Education	Chartered Architect and Chartered Project Manager	Significant policy and industry expertise	Secretary General in the Association for Consulting Architects (ACA), Advisor for Digital Catapult
I_5	Digital Lead in Cities & Development and Aviation at a consulting firm	Chartered Engineer	Manager at the Heathrow Expansion project	Expert Mappers Panel in Infrastructure at Greater London Authority
I_6	Associate Professor in Project Management and Economics	Royal Institution of Chartered Surveyors (RICS) and Association of Chartered Certified Accountants (ACCA)	Senior Cost Engineer for Translink JV at the Channel Tunnel Project	N/A
I_7	Innovation Director, Thames Tideway	Chartered engineer	Digital Innovation at Thames Tideway, 2021.	Member of i3P; Advisory to Centre for Digital Built Britain; BIM Task Force; Infrastructure Client Group
I_8	Research and teaching. Higher Education	Architect and academic	Research - Avanti	Leader of Research & Innovation at major industry body.

Table 2
Illustrative list of AEC incumbent contractors per project

Channel Tunnel	Heathrow T5	London Olympics 2012	Crossrail [9]	Thames Tideway[10]	High Speed 2
Bechtel	British Airport Authorities Ltd.	CH2MHill	Bechtel	Ferrovial Agroman UK Ltd	SNC-Lavalin
Arup	Vinci construction[11]	Laing O'Rourke	Halcrow	Laing O'Rourke Construction	Arup
Systra	Rogers Stirk Harbour + Partners[12]	Mace	Systra	Costain Ltd	Atkins
Halcrow	Laing O'Rourke – 1st tier supplier[13]		AECOM	Vinci Construction Grands Projects	CH2MHill
			CH2M Hill	Bachy Soletanche	SENER
			Nichols Group	Amey	Vinci Construction UK Ltd
			Laing O'Rourke	BAM Nuttall Ltd	Balfour Beatty Group
				Morgan Sindall Plc	Laing O'Rourke Construction Limited
				Balfour Beatty Group	Ferrovial Agroman (UK) Limited

[9] https://www.crossrail.co.uk/news/articles/crossrail-completes-design-contracts-award-process.
[10] https://www.tideway.london/about-us/the-organisation/.
[11] https://www.vinci-construction-projets.com/en/realisations/heathrow-airport-tunnel/.
[12] https://www.rsh-p.com/projects/transport/terminal-5-heathrow-airport/.
[13] https://www.irbnet.de/daten/iconda/CIB17591.pdf.

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