BALANCING OPEN AND CLOSED INNOVATION IN MEGAPROJECTS: INSIGHTS FROM CROSSRAIL

ABSTRACT

We studied the interplay between open and closed innovation at Crossrail, Europe's largest civil engineering project, aiming to build a suburban railway system in London. Our findings suggest that open and closed innovation can be combined by creating an appropriate communication and exchange environment, whose elements include organizational arrangements (e.g., team organization, and task assignment) and methods and rules of communication. We also find that innovation in megaprojects can be successfully driven when the contractors are encouraged to search for and implement incremental solutions to minor problems, not just radical and strategically relevant innovations.

Keywords: sources of innovation, open innovation, megaprojects, temporary organizations

INTRODUCTION

Megaprojects are large-scale investments aiming to design and build, under varying degrees of public and private control, physical infrastructures such as transport, water, energy, and other utility systems (Altshuler & Luberoff, 2003; Flyvbjerg, Bruzelius, & Rothengatter, 2003; Merrow, 2011). Led by a combination of a large client and a prime contractor, or joint-venture delivery partner (Brady & Davies, 2014), a megaproject is a complex temporary organization comprising a large number of firms, all contributing to realize investments ranging from $250 million to $1 billion and more (Altshuler & Luberoff, 2003; Flyvbjerg et al., 2003). Given their complexity, and the involvement of a large number of organizational and individual actors, megaprojects represent ideal settings for fostering innovation in the construction industry (Davies, MacAulay, DeBarro, & Thurston, 2014; DeBarro et al., 2015). However, researchers have only started to investigate how innovation occurs in megaprojects. Recent studies have started to address specific problems related to innovation in these settings – for example, the managerial processes involved (Davies et al., 2014; DeBarro et al., 2015), or the learning involved in creating new delivery models (Davies, Gann, & Douglas, 2009). But with few exceptions (Dodgson, Gann, Macaulay, & Davies, 2015) prior research neglects to study how the process of innovation, open and closed, is managed in megaprojects.

Innovation is defined as the development, implementation and exploitation of a novel idea, scheme, or formula (Dodgson, Gann, & Salter, 2008; Van de Ven, 1986). But how innovation is developed and implemented depends on the specific characteristics of the organizational setting. Studies of innovation have largely focused on the firm – that is, the permanent organization – to examine how it develops the capabilities to leverage innovative ideas generated in-house, through research and development (R&D), or captured from external sources (Dodgson, Gann, & Phillips, 2013). Yet, innovation in megaprojects involves more

complex processes (Dodgson, Gann, MacAulay, & Davies, 2015), which often unfold beyond the boundaries of individual organizations, as large coalitions of temporary (joint-ventures, special-purpose vehicles, or delivery partners) and permanent organizations (client, contractors, subcontractors) are established to achieve a specific goal, and then disbanded. Therefore, while business firms develop and implement innovation strategies to survive and compete in the long run, innovation in megaprojects involves attracting new ideas from multiple sources – including temporary and permanent organizations that form the supply chain – and leveraging them as effectively as possible for the duration of the project (Davies et al., 2014; DeBarro et al., 2015). The inherent innovation processes can be 'closed', when occurring internally to individual firms, or 'open', that is, undertaken in collaboration with large networks of actors including individuals, businesses, universities, and public bodies (Chesbrough, 2006).

We referred to these two dimensions – openness and closeness – to investigate the interplay between different sources of innovation in Crossrail, Europe's largest civil engineering project, aiming to build a £14.8bn suburban railway system in London by 2019. Previous research has explicated how Crossrail Limited, a wholly owned subsidiary and special-purpose vehicle of Transport for London (the client), developed and implemented an innovation strategy to help the main contractors involved in the project to generate new ideas, practices, and technologies (Davies et al., 2014). For the purposes of this paper, we studied the early outcomes of such innovation strategy to identify drivers and sources of innovation within the overall program. Our findings highlight the potential advantages of adopting open innovation in megaprojects. In particular, we illustrate the challenges and benefits associated with managing at the program level the interplay between open and closed models of innovation, and striking the right balance between the two.

INNOVATION IN MEGAPROJECTS

Megaprojects and Innovation Strategies

A megaproject is a temporary inter-organizational setting (Jones & Lichtenstein, 2008; Winch, 2014) established to build a complex, large-scale system or "system of systems" (Dvir & Shenhar, 2011; Shenhar & Dvir, 2013). A client, often a public authority, is responsible for setting up a temporary organization with the purpose of coordinating a large network of firms involved in the design, construction, and handover of the physical infrastructure, and managing the relationships with external stakeholders. To do so, the client may rely on capabilities available in-house, and/or appoint a prime contractor or delivery partner (a joint venture, or "special-purpose vehicle"). The delivery of each of the individual projects within the overall program is assigned to permanent organizations such as contractors and subcontractors.

Megaprojects represent ideal settings for fostering innovation in the construction industry. The complex exchanges taking place within these large networks of individuals and firms often encourage the adoption of novel modes of organizing, and foster experimentation with new products and practices. Such innovations often have industry-wide impacts beyond performance improvements (cf. Gann, Wang, & Hawkins, 1998). For example, pioneering megaprojects recently delivered in the UK, such as Heathrow Terminal 5 and the London 2012 Olympics and Paralympics construction program, have shown that innovation and learning can improve project performance substantially (Davies et al., 2009; Davies & Mackenzie, 2014). Although the London 2012 program did not have a formal innovation strategy, the motivational impact that working on the Olympics had on project teams (the "Olympic effect"), and the sense of urgency associated with unnegotiable deadlines imposed

by the fixed opening date, encouraged innovative ideas and solutions, as exemplified by the noteworthy re-design of the Velodrome roof (Mackenzie & Davies, 2011).

Innovation is generally regarded as the "successful commercial exploitation of new ideas" (Dodgson et al., 2013; Dodgson et al., 2008). It allows organizations to thrive in fast-changing and uncertain environments by encouraging learning through creativity and improvisation (Loch, DeMeyer, & Pich, 2011). Extant literature has investigated several dimensions of innovation in the construction industry (Manseau & Shields, 2005), including the several types and scopes of innovation (Slaughter, 1998), the inherent complexity (Gil, 2007; Shenhar & Dvir, 2013), and the related processes (Tether & Metcalfe, 2003; Winch, 1998; Winch & Carr, 2001), challenges (Gann et al., 1998; Slaughter, 1998), and impediments (Bernstein & Lemer, 1996). However, innovation in megaprojects is a relatively new and not fully understood phenomenon. A traditional concern with minimizing costs and avoiding additional risk has discouraged efforts aiming to improve project performance through experimentation and learning (van Marrewijk, Clegg, Pitsis, & Veenswijk, 2008). In fact, while innovation management tends to offset the risks and opportunities of experimentation, project management tends to associate risks with negative outcomes such as higher costs and delays (Macaulay, Davies, & Dodgson, 2014). Therefore, innovations are traditionally pursued and implemented within firms – that is, relatively permanent organizations – but formal innovation strategies do not usually exist for megaprojects intended as autonomous but temporary organizational settings (Davies et al., 2014; Dodgson et al., 2008). Although many large contractors involved in megaprojects have developed strategies and capabilities to exploit firm-level innovative ideas *across* projects, and improve their chances of survival and long-term growth (Dodgson et al., 2008), the transitory nature of project activities restricts the opportunities for innovating *within* megaprojects (Davies et al., 2014). Moreover, the temporary organizations set up for delivering megaprojects are

usually not endowed with independent innovation capabilities, and do not have specific incentives to develop them. As a result, innovation in megaprojects has generally been limited to seeking new ways of controlling and reducing costs and risk, or enabling earlier project completion.

However, researchers have started to demonstrate that a different approach can be adopted. Recent empirical studies have found that the performance of megaprojects can be enhanced by embedding in the project activities and routines the technologies and best practices developed on other programs, and devising specific mechanisms for fostering innovation, such as new procurement, contract, and organizational strategies (Davies et al., 2009). For example, the use of integrated project teams, and appropriate procurement routes such as the NEC3 Engineering and Construction Contract[1], play an important role in stimulating contractor-led innovation (Hansford & Pitcher, 2013). Early engagement of contractors at the design stage encourages the proposal and evaluation of innovative solutions, incentivizes collaborative behaviors, and mitigates adversarial relationships, conflict, and opportunism. The use of target-cost forms of contract also provides the opportunity to attain greater rewards, and sets incentives to implementing innovations. These findings are encouraging scholars and practitioners alike to further investigate the factors that enable innovation in megaprojects.

Closed and Open Innovation in Megaprojects

Innovation can be studied along several dimensions. With regard to its magnitude and impact, it can range from minor, incremental improvements (von Hippel, 2005) to the pursuit of fundamentally different approaches leading to radical breakthroughs (Bayus, 2013). A second dimension concerns the entity being innovated – this can be a firm's product, service,

[1] The NEC3 Engineering and Construction Contract is a standard contract created by the Institution of Civil Engineers to stimulate good project management practice on civil engineering and construction projects.

process, or overall business model. A third dimension particularly relevant to this study pertains to where, within the complex megaproject organization, innovative ideas are generated – that is, the sources of innovation. We know that innovative ideas can originate from users, manufacturers, or suppliers, depending on the specific relationship the potential innovators have with the product, process, or service being innovated (von Hippel, 1988). In certain industries, users play a key role in bringing forth new ideas and promoting improvements of existing products and services that solve problems for a limited number of beneficiaries (von Hippel, 1988, 2005). In projects, however, it is the producer layer – that is, the firms responsible for carrying out the project, as well as their suppliers – that generally drives most innovations (Dodgson et al., 2015; Gann, 2001), although user-driven innovations can still arise from the parties involved in the use of the project output, such as operators, consumers, and end-users. Extant literature has underlined that in multifirm collaborative settings – of which megaprojects are a noteworthy example – certain organizations play a fundamental role as lead innovators (Baldwin & von Hippel, 2011), in that they guide the innovation process for the development of novel products and/or the discovery of new functions (von Hippel, 2005). But although it is reasonable to expect that within the complex setting of a megaproject lead innovators will certainly exist, little is known about the interplay between ideas generated within the individual projects and ideas borrowed from other projects, or from the external environment. And this makes it difficult to predict exactly where the most valuable innovations arise and out it can be leveraged (von Hippel, 2005).

Until recently, internal R&D capabilities were viewed as a key strategic asset for organizations, because they are often able to erect barriers to entry in a given market or whole industry (Chesbrough, 2004). This form of closed innovation usually involves seeking and generating ideas from within the organization, in a way that makes firms self-reliant in terms

of availability, capability and quality of the new ideas (Chesbrough, 2006). The development and increasing complexity of modern technologies have driven the transition towards an open and distributed form of innovation process (Chesbrough, 2003; von Hippel, 2005), which involves attracting and implementing ideas from other firms and organizations, or even large and dispersed "crowds" of non-experts (Bayus, 2013). Introducing ideas from outside the firm increases the possible sources of innovation, but also places emphasis on a new range of capabilities required to establish and develop weak-tie collaborations (Chesbrough, 2004), manage external proponents of unsolicited innovations, allow intellectual property and ideas to flow freely, strengthen problem-solving capabilities, and maintain an overall nimble and proactive organization (Chesbrough, 2003). On the one hand, open innovation can lead to transaction cost advantages over organizations with large in-house R&D capabilities (Baldwin & von Hippel, 2011). On the other hand, it also entails the challenge of controlling a large amount of potentially innovative ideas, many of which are low quality (Alexy, Criscuolo, & Ammon, 2012). In fact, an important precondition for open innovation is the focal firm's engagement with its organizational ecosystem (Alexy et al., 2012). By voluntarily and strategically revealing its own innovative knowledge and ideas to the ecosystems, the firm can source creative solutions to particular problems or obtain support to overcome specific obstacles (Alexy, George, & Salter, 2013). Opening up innovative ideas also raises issues over intellectual property, and entails that the firm put in place appropriate mechanisms of protection – for example, patents, copyright management systems, trademarks, industrial designs, and so forth – without which securing successfully the economic benefits of innovations can be complicated and expensive. Despite the inherent challenges, individuals and organizations are increasingly willing to reveal innovative ideas to their ecosystem and the public domain (Alexy, Criscuolo, & Salter, 2009). As a result, innovation management is increasingly becoming a social endeavor, whose effectiveness and

success increasingly depend on focal organization's ability to pursue high quality of innovations (as opposed to the quantity of new ideas), and put in place organizational mechanisms that help individuals and teams to discuss, select, and improve their ideas before implementing them (Kijkuit & van den Ende, 2010). However, although extant literature has investigated the different sources of innovation extensively, our understanding of how closed and open innovation interact in large multiorganizational programs is still limited. Hence we ask, *how can the interplay between sources of innovation be managed and leveraged in megaprojects?*

In the remainder of the paper, we provide an account of the research design and methods adopted to answer this question, illustrate the findings from our analysis, and discuss the interplay between sources of innovation at Crossrail. As Crossrail was in the construction phase at the time of data collection, we could not include in our analysis innovations implemented by end-users when the railway became operational. We focused on the major sources of innovative ideas on the producer's side (the network of firms involved in the delivery of the megaproject), investigating the drivers behind such innovative ideas, and paying particular attention to how the interplay between closed and open innovation was managed and leveraged across the program.

METHODS

To answer the above question, we studied Crossrail, the first megaproject in the UK's construction industry to introduce a formal innovation strategy, known as the Crossrail Innovation Program. Previous innovations in megaprojects have aimed to enact unique delivery mechanisms, such as the "T5 Agreement" for Heathrow Terminal 5, but have not sought to develop and implement innovations as a strategic priority of the megaproject itself.

Crossrail has challenged previous approaches by devising a groundbreaking innovation strategy, and putting in place specific organizational arrangements for encouraging, funding, and implementing innovations in each of the projects that were part of the program. (Davies et al., 2014). To create opportunities for value creation during the delivery of the megaproject, the innovation program incentivized the generation of innovative ideas within each project, as well as the implementation of ideas proposed by other projects, in two ways: 1) through a system of competitions and awards, the Crossrail Innovation Competitions; and 2) by formally documenting each innovation, and publishing it on a web-based repository (or portal) called 'innovate18'.

Adopting a case study design (Yin, 2013), we focused on the temporary organizations that generated, developed, and implemented innovative ideas on site, during the execution phase: these were Crossrail Limited (with its various functions and departments), and 17 projects that were being delivered as part of the overall program at the time of our data collection and analysis. To such purpose, we used a database through which Crossrail Limited[2] captured innovative ideas generated within its own departments and in each of the projects, and monitored their adoption and implementation across the program.

The database was a particularly rich source of data. For each innovation, it reported: a) a title, reference number, and date of submission; b) a detailed description of the innovative idea (up to a few hundred words); an illustration of the innovation context, that is, how the project by which the innovation was put forward as well as the program overall could benefit from its implementation (up to a few hundred words); and c) information about the submitter (full name, parent company, and contact details). Innovations were grouped by theme and subthemes. For example, the theme "Sustainable solutions" comprised subthemes such as "Environmental", "Economic", and "Social", whereas the theme "Digital-physical

[2] We refer to both Crossrail Limited and its program delivery partner, Transcend (a joint-venture of AECOM, CH2M Hill, and Nichols Group), as one organization, which is responsible for managing the Crossrail megaproject and, particularly relevant to this study, the Crossrail Innovation Program.

integration" included the subthemes "Smart technologies", and "Building Information Management" (BIM). Specific functions of the database allowed program managers to monitor whether and how the innovation progressed from submission to implementation, and insert updated information and comments about the process. Another important feature of the database was the record of when innovations submitted by a given project were also implemented by other projects. Labeled as "Pinch with Pride", the replication of innovations from project to project was seen by program managers as particularly beneficial to the Crossrail program overall. Consequently, it was possible for a project to have the greatest number of implemented ideas simply by "pinching" and replicating innovations from other projects. Sustaining "Pinch with Pride" practices allowed the project teams to raise and explore in advance any issues concerning, for example, the intellectual property of successful innovations.

We performed a qualitative and quantitative content analysis of the information contained in the database, especially for what concerns the description of innovative ideas, the illustration of the innovation context, and the anticipation of expected benefits. This allowed us to identify patterns and trends of the innovativeness of specific projects and their principal contractors. In particular, we studied the innovative ideas submitted to the innovation competitions to assess the quantity and quality of such ideas, and understand whether common elements could be found across projects and contractors. This detailed appraisal of the database allowed us to identify projects, contractors, and individuals that were most prolific in terms of generating innovative ideas, and select 'hotspots' of innovation for further collection and analysis of qualitative data.

After identifying the projects that performed best in terms of number of submissions, we interviewed relevant informants within those projects to explore drivers and sources of innovative ideas, and identify factors involved in their generation, development and

implementation. We were granted access to a complete and detailed contact list of all project staff to select informants for in-depth semistructured interviews. We selected individuals who were best positioned to provide insights about the research problem by virtue of their involvement in core activities for the management of innovative ideas, as documented in the innovation database, and through the details of innovations published on innovate18. After email exchanges aiming to inform interviewees of the format and purpose of interviews, we met them during visits to the project sites. Interviews were recorded and lasted between 45 and 60 minutes. Since the topic and purpose of the interviews were central to the interviewees' day-to-day activities, they were particularly motivated to contribute relevant information and insights into the research, and our conversation with them resulted particularly dense with insights.

We employed an interview guide that served the twofold purpose of maintaining consistency across informants, and orientating our free-flowing conversations along a set of clear goals of data collection. The first questions aimed to investigate how the innovation program was viewed within the projects, what drove the submission and implementation of innovative ideas (for example, purposes of cost reduction or technical improvement), and how project teams developed innovative ideas generated within the same project, or in other projects. As the interviews proceeded, further questions explored aspects such as: a) the role individual contractors played in encouraging and incentivizing internal innovation, as well as capturing external innovations; b) the alignment between project and corporate innovation strategies; c) whether project teams were given key themes, or areas, to focus on for identifying opportunities to innovate, or were left free to explore opportunities autonomously; d) the relationship between the main contractors' head offices and the innovation program; and e) whether the encouragement to generate innovative ideas was also extended to suppliers. We kept adding new informants as long as new interviews provided new and

relevant insights, up to a point of saturation achieved with 15 interviews. Table 1 reports for each informant the job title and the project in which they were involved; Table 2 reports representative interview data.

[Insert Table 1]

[Insert Table 2]

Interview data were analyzed by extracting excerpts that were relevant to the research problems, and breaking them down into incidents that referred to specific concepts. Incidents were then grouped and compared across informants and along themes of inquiry – for example, "drivers of innovation", "sharing innovation", "sources of innovation", and so on. We also used documents as an additional data source; these included internal reports and presentations, pages of Crossrail's website, company archives, and videos.

INNOVATION AT CROSSRAIL

Organizing for Innovation

The ambition of Crossrail Innovation Strategy was to create value not only for the Crossrail program, but also for the UK construction industry in general. Outlined in Figure 1, such vision conceived the construction of a world-class railway as an opportunity to promote innovation by taking into account lessons learned in previous megaprojects (e.g., Heathrow Terminal 5, and London 2012 Olympics), but also pass learning on to future projects, such as Crossrail 2, and Thames Tideway Tunnel. According to Andrew Wolstenholme, Crossrail's chief executive officer, "innovation is not [necessarily] coming up with unique new products; it's about creating value by bringing ideas together, through the design, construction, and operational phases". As the majority of the about 14,000 people working on Crossrail during the peak construction period were employees of the supply chain rather than staff of Crossrail

Limited, it was clear that most innovative ideas had to be pulled up from the supply chain and brokered across the program (Macaulay et al., 2014). Crossrail Limited's program board adopted an open innovation model, and set up an organizational structure running in parallel with the program's organization, and specifically dedicated to managing innovation (illustrated in Figure 2).

[Insert Figure 1]

[Insert Figure 2]

At the program level, this structure was formed of four bodies sitting within and organized by Crossrail Limited. At the top, the Crossrail Innovation Forum, an executive body comprising Crossrail executives, members of research institutions, and representatives of the supply chain, was responsible for setting up and directing the innovation program, and reviewing and ratifying the proposed innovations. Under the Forum's guidance, the Innovation Working Group, which comprised industry experts and representatives of the main contractors, periodically held innovation competitions to evaluate the innovative ideas generated across the program, and select those worthy of being funded for further development and implementation (financial support for the competitions was provided by all tier-one suppliers, principally the construction organizations). In close collaboration with the Innovation Working Group, a third body, the Crossrail Innovation Team, mobilized the entire supply chain, and encouraged the project teams to contribute innovative ideas into the program, and implement valuable ideas published by other projects through innovate18. Further support to innovation initiatives was ensured at the program-level by Functional Sponsors, that is, specialists employed in functional areas of Crossrail Limited, such as finance, planning, operations, marketing, information technologies, and logistics.

At the project level, key to the success of the innovation program were the Innovation Champions. These were individuals appointed by contractors and delivery teams to stimulate

the generation of new ideas within projects, and develop ideas funded through the innovation competitions. Finally, a broad base of potential innovators engaged with the innovation program at the project level; these included firms working on projects as members of the supply chain, as well as management researchers from academic institutions and corporate R&D departments. The role of these categories of stakeholders was to formalize and submit innovative ideas, create (where applicable) prototypes and/or working examples, and collaborate with other parties at the industry level to develop the innovations that had received funding and support.

Innovative Projects and Contractors

At the time of our study, Crossrail comprised 17 major projects, carried out by 10 principal contractors – Table 3 reports, for each project, the responsible contractor, and the type of output delivered. All projects used target cost contracts with a pain/gain share option[3] as a way to incentivize the pursuit of innovation by project firms. During our data collection, 458 innovation ideas with variable degrees of quality and maturity had been submitted to the innovation database, most of which were still being assessed for funding and development purposes. 352 ideas came from projects, whereas 106 (about a fifth of the total) had been generated within functional departments of Crossrail Limited. Table 4 provides an account of the submitted ideas for two categories of sources: projects (first part of the table), and functional departments of Crossrail Limited (second part of the table). For each source, the table reports the number of ideas that were funded, implemented, published (on Innovate18), and "pinched" (or replicated) by other projects. The last column of the table shows the number of innovations that each project "pinched" from other projects.

[Insert Table 3]

[3] Target cost contracts enable the contractor to share in the benefits of cost savings, and bear some of the client's cost in case of cost overruns. A pain/gain share option is a contractual mechanism by which the financial effects of cost savings and cost overruns can be shared among the client, contractor, and supply chain.

[Insert Table 4]

Bond Street, Paddington, and Western Tunnels were leaders in number of submissions, whereas PiP, Wallasea, Victoria Dock Portal, and WHI-LIS (all in the construction phase at the time of data collection) only submitted few ideas. Three of the five most active projects, Paddington, Bond Street, and Eleanor Street & Mile End Park Shafts, had the same principal contractor, and other main contractors with multiple projects seemed to maintain similar levels of submissions across projects. For example, Tottenham Court Road, and Liverpool Street (respectively 19 and 26 submissions), had the same contractor, who was responsible for 18 of the 19 submissions at Tottenham Court Road. An exception was Custom House, which had only 6 submissions although the contractor was one of the leading submitters on other projects. By looking closely at the formation and structure of the project organizations, we noted that out of 17 project coalitions, 9 were joint ventures, and these joint ventures were responsible for most submissions.

Beyond the mere quantitative information of the number of submissions, we took into consideration the quality of each submission by ascertaining which ideas had been, published, implemented within the proponent project, or replicated in other projects. From this point of view, the principal contractors for Paddington, Bond Street, and Eleanor Street & Mile End Park Shafts were the leading submitters with all three projects close together. Next were Western Tunnels, and Farringdon, which had the same main contractor. Notably, Thames Tunnel submitted 23 ideas of which 18 were published. Overall, projects involving the construction of brand new stations were the most innovative. Although one might expect that this was due to the larger size and higher complexity of such projects, an analysis of the contract value showed that other projects with similar size and complexity, such as the tunneling projects, performed worse, whereas certain low-value contracts outperformed high-value contracts in number of submissions.

Open Innovation – Not the Full Picture

In the second part of our study, we combined the analysis of the database with the collection and analysis of qualitative data, mainly interviews and documents. In particular, interviews provided rich insights into the drivers and sources of innovation initiatives. Interestingly, none of our informants mentioned the reduction and control of costs as main drivers. Instead, they underlined that the main purpose of innovative ideas was to realize engineering solutions that were "technically better" – for example, because they enabled improvements in safety, or environmental impact and sustainability. Moreover, when asked about the impact of innovative ideas, informants often referred to benefits for Crossrail, intended as the overall program, and for the construction industry in general, rather than particular gains for individual companies.

The main drivers were health and safety, and the environment. Innovative ideas in these areas included, for example, employing ultra-low-carbon concrete, designing a system for generating electric power from the friction of the train wheels, installing automatic fire-suppression systems, conducting safety peer reviews, and devising protocols and procedures for an "ethical supply chain in construction" (Table 5 reports exemplary descriptions of innovative ideas excerpted from the innovation database). Informants concurred that innovations in these areas tended to yield "quick wins" at the innovation competitions, as they were linked to important priorities for both Crossrail Limited and the main contractors. As for the types of innovations, informants explained that all principal contractors found it difficult to implement new ideas in the use of construction materials and techniques for two main reasons. First, both materials and techniques were usually dictated in the contracts, leaving little leeway for alterations during execution. Second, this type of innovation is not usually viable because the construction stage occurs too late in the project lifecycle. In fact,

all interviewees expressed a sense of frustration about the fact that numerous ideas about new materials and techniques could not be implemented. Despite the constraints, however, some project teams such as those involved at Bond Street, and Paddington, adopted a proactive approach to innovation, and used current and forthcoming project activities as opportunities for generating innovative ideas, instead of simply responding to problems encountered.

[Insert Table 5]

Another important driver of innovation mentioned by interviewees, especially those involved in the Paddington, Bond Street, and Eleanor Street & Mile End Street Park Shafts projects, was the project teams' ambition to become the "top innovators" in the program. This led some teams to engage with the "Pinch with Pride" initiative, encouraging both the replication of their innovative ideas in other projects, and the adoption of ideas generated elsewhere.

Overall, the proponents of innovative ideas within the projects mostly relied on the support provided by from Crossrail Limited rather than their parent companies, where "innovation discussions" were not as frequent and supported. In fact, although all parent companies had explicit innovation objectives at the corporate level, innovation was not really pushed down to the Crossrail projects and then back the supply chain. Instead, the specific thrust towards innovation was driven by Crossrail, which constantly encouraged the project teams to get involved in multiple ways – for example, by giving regular presentations to people working on sites, promoting and communicating broadly their initiatives, and promoting further involvement at both project and program levels. In the more active projects, workers were briefed almost daily about how to identify, communicate, and submit new ideas. The use of workshops held by principal contractors to engage with subcontractors also emerged as another effective tool to raise awareness of the innovation program, and encourage participation. This kind of mobilization ensured that innovation initiatives were

aligned with the core project objectives – such as health and safety, quality, and the environment – but also that engagement at a higher level was observed from people working on site rather than office personnel. In general, the innovation program was communicated as an opportunity to make improvements and tackle problems, rather than a more radical initiative to address "big issues".

Notwithstanding the remarkable benefits yielded by Crossrail Limited's pioneering model of open innovation, the innovation program did not draw from many pockets of closed innovation, which were generated and implemented within the boundaries of the same organization. For example, some innovations remained closed when, albeit shared through the database, they were replicated across projects by the same contractor – as demonstrated by the data about the contractor of Liverpool Street, Custom House, and Tottenham Court Road. However, a more important category of closed innovations included ideas that the contractors and subcontractors decided not to share for strategic reasons. Our interviewees often mentioned "concern" about unveiling innovative solutions, especially in the area of construction methodologies, which were likely to give the firm a considerable advantage over competitors.

The supply chain was another important source of innovations, but its contribution varied depending on whether the contractors needed the contribution of suppliers to carry out project activities. Notably, limited supplier involvement existed for all of the projects, so that innovative ideas tended to originate from subcontractors rather than suppliers. Site personnel, such as operatives and works managers, played an important role in identifying ideas and imagining possible applications. In some projects, innovation groups were formed to stimulate and support project staff to put forward new ideas, and then help advance them through discussions and collective evaluations. This allowed to increase both the quantity and quality of new ideas. Some projects had rather large innovation groups with more individuals

involved, and a greater number of innovative ideas generated. In other projects – such as Bond Street, and Paddington – regular project staff (i.e., employees that were not members of innovation groups) represented the main source of innovative ideas.

Replicated Innovation

The "Pinch with Pride" scheme encouraged the mutual sharing of innovative ideas among projects with the purpose of multiplying the opportunities for the adoption and implementation of innovations that were deemed particularly valuable. The scheme enhanced the project innovativeness by reducing cross-project transaction costs, but it also helped improved performance by creating conditions for evolutionary development of innovative ideas. As Table 4 shows, not all projects engaged with "Pinch with Pride", and many projects played no role in either generating new ideas useful to other projects or replicating ideas generated elsewhere. For the most innovative projects, the scheme did not play a significant role in terms of cumulatively increasing the number of innovations, but noticeable engagement existed within the project teams and the contractors involved. For example, the main contractor for Liverpool Street was one of the leading submitters of ideas then replicated elsewhere, but in this case the "pinching" is partially explained by the fact that the contractor was involved in two other projects (Custom House, and Tottenham Court Road), so that some of the cross-project implementations might be seen as brokered by the contractor itself. Liverpool Street was highly prolific of ideas that were replicated elsewhere, but had not yet implemented any ideas from other projects at the time of our study. In general, station projects were the most active ones in replicating innovations, probably due to complexity of this type of projects, and the related need to integrate the numerous systems typically present in train stations.

Our informants underlined that the Crossrail Innovation Team played a key role in encouraging the replication of innovations, and providing the support that was often lacking on the contractors' side. Indeed, Crossrail Limited had committed people's time and other organizational resources to nurturing and implementing innovations, whereas the project companies encountered several problems and constraints such as the scarce communication between the head office and the project teams, particularly about the opportunities to replicate innovations. Also, corporate influence on the innovation program tended to be weak because replicating innovations was seen as a more demanding task compared to implementing ideas that had been generated and developed within the project. An additional constraint was the lack of guidance about how to engage with the supply chain, particularly how to participate in innovation competitions.

The principal contractor for Paddington, Bond Street, and Eleanor Street & Mile End Street Park Shafts was the most active in sharing innovation across projects. This contractor had significant corporate support for replication. Workshops were held quarterly among the projects' innovation groups with the aim of sharing knowledge, circulating successful ideas, and discussing the problems experienced, and the possible solutions. Replication thus "facilitated learning and idea discovery", and often "prevented repeating the same mistakes across projects". Replication practices were sustained through the central innovation database and the innovation competitions. For example, to identify innovations potentially applicable to forthcoming project activities, the Paddington, Bond Street, and Eleanor Street & Mile End Street Park Shafts projects searched the Crossrail innovation database recurrently, and this allowed Paddington to achieve a rather high number of replicated innovations. The purpose of the innovation competitions was to award financial funding for the development of proposed innovations, either through the competition scheme or via a Delegated Authority

from the innovation program. Table 6 details the funds awarded in the first year of the program.

[Insert Table 6]

Station projects dominated the competitions, whereas tunnel projects only had four awards. The most prominent project was Paddington, with funding awarded in all three rounds. This success is partly explained by the fact that Paddington incentivized project staff with non-monetary rewards such as gift cards. The main contractor for Paddington, Bond Street, and Eleanor Street & Mile End Street Park Shafts won eight awards in total. The outstanding engagement of this contractor was underscored by its participation in all rounds of competitions, an overall awarded amount equal to 46% of allocations, and the highest single award (£59,000). The main contractor for Custom House, Liverpool Street, and Tottenham Court Road was the next second successful contractor with three awards, each attributed to the respective projects.

DISCUSSION

In this section we discuss how our findings further our understanding of the interplay between open and closed innovation in megaprojects. As underlined by extant studies, megaprojects are infrequent undertakings which generally tend to underperform from economic, operational, and environmental points of view (Flyvbjerg et al., 2003). Prior studies of innovation in megaprojects have focused on the use of lessons learnt from other projects, and the creation of new types of project delivery models (Brady & Davies, 2014; Davies et al., 2009). However, extant research has largely neglected the study of localized, sporadic, and generally unmanaged pockets of innovation present within megaprojects, and ranging from incremental improvements of existing products, tools, and processes to the

pursuit of more radical ideas (Bayus, 2013). Crossrail has pioneered the creation of systematic processes and organizational arrangements for supporting, enhancing, and exploiting the innovation capabilities possessed by many employees of the organizations taking part in the program (Davies et al., 2014; Davies & Mackenzie, 2014), providing a unique opportunity for studying the diverse sources of innovation in these peculiar settings. In many respects, Crossrail Limited put in place a program-wide project learning process with dedicated management support, and related support systems and resources (Chronéer & Backlund, 2015). Our study focused on the major firms involved in such process: Crossrail Limited, and the principal contractors delivering major projects. We found that, while some contractors were actively engaged in the innovation program and embraced the model of open innovation proposed by Crossrail Limited, others were more reluctant to share particularly valuable ideas generated by their employees, and rather focused on the successful completion of the respective projects within time and budget. Such circumstances led to the simultaneous presence of open and closed innovations across the program.

The experience of Crossrail suggests that open innovation in a megaproject can be more effectively driven when the main contractors are encouraged to search for and implement innovative solutions to minor problems. In fact, the opportunity for incremental learning was the main apparent reason why some principal contractors participated actively in the innovation program, particularly for the part that involved replicating innovations to achieve continuous improvements in performance. As a result, the majority of submissions aimed at incremental innovations, rather than radical ones. This is partly due to the fact that radical innovations generally require the contribution of large multidisciplinary teams, and are difficult to implement when the project has entered the construction phase. A similar explanation was provided by our interviewees who emphasized that contractors pursued radical innovations of construction processes to gain a long-term competitive advantage.

Given their strategic relevance, the development of this category of innovative ideas was not disclosed by the project firms for the purpose of participating in innovation competitions. Such circumstance seems to be supported by the analysis of the drivers of innovations.

Achieving successful innovation outcomes was often difficult for suppliers that were involved in the project for a short time and/or limited scope. Although, many innovative ideas were generated by subcontractors and small firms in the supply chain, some contractors often hesitated to provide the support needed to take ideas forward and implement them across the program. However, the most innovative projects were led by contractors that actively encouraged a wide range of employees to submit novel ideas, including both office staff and site personnel, confirming the importance of expanding as much as possible the base of potential innovators (Bayus, 2013). The more complex projects combined open and closed innovation by engaging with subcontractors, and involving non-project actors too. This allowed the project teams to draw from large crowds of potential innovators and benefit from a wide range of technical disciplines and competences.

Indeed Crossrail's innovation activities supported a temporary coalition of organizations which functioned as a business ecosystem. Business ecosystems are settings where multiple players hold ambiguous relationships of cooperation and competition while contributing to a common goal, generally without direct contractual arrangements (Moore, 1993; Moore, 1996; Moore, 2006). Although all the organizations on the megaprojects were interconnected through contracts, innovation was not measured by performance indicators, nor was it used to regulate the relationships between the parties. Instead, the success of the innovation program rested on Crossrail Limited's ability to create a cooperative culture, possibly supported, but not necessarily enforced, by the use of collaborative forms of contracts (notably, elements such as intellectual property were not raised by any of the interviewees as barriers to innovation).

Our findings, therefore, suggest that innovation can be harnessed within a large project coalition when the program management shapes the coalition as a community of practice, and builds it around the common goal of innovation so that individual advantages are combined with program-level organizational benefits (Lee, Reinicke, Sarkar, & Anderson, 2015). Figure 2 shows that, despite the boundaries between projects, and the usual reluctance of contractors to share innovative ideas that have strategic impact, formal and informal practices of communication can still be put in place to encourage knowledge exchange and sharing between teams and projects (Mueller, 2015). From a project and program management point of view, this provides insights into the relationship between the program and the projects, and the most suitable structure and composition of the program organization to support innovation. Indeed, our findings suggest that innovation strategies for megaprojects are more likely to succeed when individual projects "pinch" innovations from other projects, and this is greatly facilitated when the main contractors undertake multiple projects within the same program.

Interestingly, the sources of innovation (both open and closed) that we identified were within the control of the principal contractors, as well as Crossrail Limited. This supports the idea that contractors have great influence on the outcome of innovative efforts in megaprojects (Gann, 2000; Hansford & Pitcher, 2013), and suggests that these firms should probably be more actively involved in deciding the features and shaping the organization of an innovation program than they were on Crossrail. As a matter of fact, the projects that consistently raised awareness of the innovation program among their employees were the most successful in submitting new ideas and obtaining funding through the innovation competitions. The literature does not provide precise insights into the importance of raising awareness among employees about generating and capturing innovations, but in temporary

organizations this seem to emerge as an essential means to ensuring successful engagement with structured innovation initiatives.

The fact that the ideas submitted to the program were discussed and filtered through multiple layers of assessment, from the project up to the program level, implied the involvement of many people performing different roles to develop each new idea. Extant literature has found that particularly strong personal ties between people in different parts of a large organization expand the chances of successful adoption and implementation of new ideas (Kijkuit & van den Ende, 2010). Although the temporary nature of projects might not allow sufficient time for establishing such ties, the experience of Crossrail shows that managers can effectively create the conditions for communicating and sharing ideas, and use information systems to foster innovation (Winch, 2010; Winch, 2015) and enhance "network connectivity" (Björk & Magnusson, 2009) within and across the organizations of the megaproject. The projects that were most successful in the innovation submissions had the largest and most active working groups. Overall, we learnt that open and closed innovation can be combined and leveraged together by creating an appropriate communication environment, whose elements include not only organizational arrangements (e.g., team organization, and task assignment) but also the definition of methods and rules of communication (Phillips, 2014).

Table 1. Details of Interviewees

Date	Job title	Project
28/05/14	Environmental Advisor	Farringdon
28/05/14	Assistant Engineering Manager	Farringdon
29/05/14	Lead Field Engineer	Bond Street
30/05/14	Site Engineer	Bond Street
30/05/14	Site Manager	Liverpool Street
04/06/14	Section Engineer	Bond Street
06/06/14	Community Relations Advisor	Liverpool Street
06/06/14	Site Manager	Bond Street
11/06/14	Trainee Quantity Surveyor	Paddington
18/06/14	Construction Superintendent	Paddington
25/06/14	Field Engineer	Paddington
30/06/14	BIM Manager	Paddington
30/06/14	Head of Innovation	Crossrail Innovation Forum
07/07/14	Engineering Excellence Lead Structural Director	Crossrail Innovation Forum
22/07/14	Group Innovation and Knowledge Manager	Crossrail Innovation Forum

Table 2. Display of representative interview data supporting interpretations

Project Delivery Managers	Principal Contractor Managers
Drivers of Innovation	
"Technical complexities and construction solutions are more at the design stage rather than the project execution stage"	"Project complexity is a perfect breeding ground for generating ideas."
"Innovation is not only applicable to the project, but to all of the Crossrail program."	"Innovation is needed to stay one step ahead."
"Most ideas are best practice rather than innovative. It's very difficult to come up with something that is [radically] innovative."	"With margins so tight and most contractors struggling to generate a profit, cost savings are a key motivator to generating ideas."
"Innovation is the only way you can get advances in industry for process improvement. It's the evolution. I can't see why you wouldn't do it."	"Innovation gives certainty of outcome and reduces risk. There is massive risk when you are building a station in Central London."
"How do we build in a better way?"	"With construction innovations you are focusing more on the process type of stuff and have to overcome cultural barriers and a need for a larger amount of investment."
"The nature of Digital Engineering is innovative anyway."	
Limitations of the Innovation Program	
"People get stuck in with the day-to-day and without a set time to think outside the box it is very difficult to come up with innovation and to progress ideas."	"Innovation is not a key performance indicator on the project."
"The level of funding available that is out there has weaned a bit somewhat. It could do with invigorating again somewhat. The Principal Contractor isn't actively seeking it out."	"Trades are very proactive in producing ideas."
"Although innovation is not a key performance indicator for the project, the working group has set itself a target of ten shared innovations for this financial year."	"Innovation is not well integrated into the project team and its performance metrics."
	"It's easier at a corporate level to get buy-in to innovation than at the project level."
	"I doubt suppliers even know about the Crossrail Innovation Program. That would be down to procurement to manage."
Innovation Potential	
"We have been a bit heavy on the Health & Safety innovations. They are easier to share. There is less of a concern that we are giving away what gives us the edge. […] We haven't had enough construction type innovations as you would. This is definitely the nature of the business, that the Principal Contractor doesn't want to give away these ideas."	"Process improvement rather than project complexity generate the ideas."
"Less construction methodology ideas, as they provide greater competitive advantage."	"Speaking to colleagues and past experience is key. Word of mouth plays a big influence."
"Lots of ideas but most are not applicable to the projects."	"Agents are key individuals in finding innovation. They are a good liaison between the site office and the operatives. They can see where the site is trying new things."
"The ideas you get site operatives tend to be small-beer types of ideas. You know that is a smart way of installing a site hoarding light. The grander schemes are probably from the engineers and office-based roles due to the nature of their roles."	"The Working Group has been key to produce ideas. When one idea comes in, we discuss it and we ping-pong it about to challenge the idea."
	"Innovation is sold to the site staff as a better way of working, not as innovation. This generates the ideas which develop into the innovation."
Sharing innovation	
"I definitely think there is a high level of cross-pollination of ideas between sites within the parent company boundaries. However, they wouldn't actively invite Crossrail into that."	Most of the shared ideas are best practice; it is not really [radical] innovation. It's great, but it's not breakthrough, and will not revolutionize the way we do things."
"A lot of cross-pollination of ideas between sites with the same Principal Contractor."	"Documenting the innovation achieved is a challenge, and this needs to be addressed."
	"Innovation may be happening on site but it is not communicated and shared. Engineers are probably doing innovation but they are not communicating it."
	"Corporate influence is low on the project and is more focused on the individuals."

Table 3. List of main projects within Crossrail

Project	Principal Contractor	Type of output
Bond Street	PC5	Underground station
Connaught Tunnel	PC6	Tunnels
Custom House	PC4	Above ground station
Eastern Tunnels	PC9	Tunnels
Eleanor Street & Mile End Park Shafts	PC5	Access and ventilation shafts
Farringdon	PC1	Underground station
Liverpool Street	PC4	Underground station
Paddington	PC5	Underground station
Paddington Integrated Project (PiP)	PC10	Underground station
Pudding Mill Lane	PC3	Railway-tunnels connection
Thames Tunnels	PC8	Tunnels
Tottenham Court Road	PC4	Underground station
Victoria Dock Portal	PC6	Railway-tunnels connection
Wallasea	PC7	Creation of a nature reserve
Western Tunnels	PC1	Tunnels
Whitechapel	PC2	Underground station
Whitechapel-Liverpool Street (WHI-LIS)	PC2	Tunnels

Table 4. Innovation Generated in Projects, as opposed to Crossrail Functions

Crossrail Projects	Submitted	Funded	Implemented	Published	PwP OUT	PwP IN
Bond Street	59	2	1	35	4	5
Connaught Tunnel	10	2	1	3	-	-
Custom House	6	1	-	5	-	-
Eastern Tunnels (incl Limmo)	16	2	1	7	1	1
Farringdon	23	-	-	14	-	-
Liverpool Street	26	1	2	9	-	-
Eleanor Street & Mile End Park Shafts	25	1	1	16	4	2
Paddington	69	4	3	36	2	2
Paddington PiP	1	-	-	-	-	-
Pudding Mill Lane	4	-	-	4	-	-
Thames Tunnels	22	-	-	18	1	1
Tottenham Court Road	19	1	-	1	1	1
Victoria Dock Portal	4	-	-	1	-	-
Wallasea	1	-	-	-	-	-
Western Tunnels	43	-	1	16	-	-
WHI - LIS Tunnels	5	-	-	3	-	-
Whitechapel	19	1	-	13	5	5
Total	**352**	**15**	**10**	**181**	**18**	**17**
Crossrail Limited Functions						
Chief Engineer's Group	6	3	2	1	-	-
Commercial Services & Contract Admin	1	-	-	-	-	-
Cost	1	-	-	-	-	-
External Affairs	2	-	-	1	-	-
Field Engineering	5	-	-	-	-	-
Finance Operations	1	-	-	-	-	-
Health & Safety	3	-	-	-	-	-
Instrumentation & Monitoring	2	1	-	-	-	-
Internal Communications & Organizational Effectiveness	1	-	-	-	-	-
IT	9	-	-	-	-	-
Land & Property	7	-	-	3	-	-
Logistics	1	-	-	-	-	-
Operations	18	-	-	-	-	-
Planning	1	-	-	-	-	-
Programme Controls	3	-	-	1	-	-
Rolling stock and Depot	4	-	-	-	-	-
Strategic Projects	14	-	1	-	-	-
Surface	1	-	-	-	-	-
Sustainability and Consents	9	2	-	-	-	-
Systemwide - Main Works	7	2	-	-	-	-
Technical General	3	-	-	-	-	-
Technical Information	7	-	-	1	-	-
Total	**106**	**8**	**3**	**7**	**-**	**-**

PwP OUT: Innovations “pinched with pride” by other projects. PwP IN: Innovations “pinched with pride” from other projects.

Table 5. Examples of Innovative Ideas (Excerpts from the Innovation Database)

Train Loading Data to Disperse Passengers on Platforms. "Crossrail trains are all fitted with a basic load-sensing apparatus that determines through suspension deflection how many passengers are in each coach. The data is downloaded 'live' using existing technology in tunnels. This innovation involves the creation of software based system allowing interrogation and display of data that allows platform-based Customer Information Screens in Central Stations to show where the train is most crowded. This will then allow customers to disperse along platforms to a less-congested part of the train before the train arrives. More even passenger distribution allows for more efficient use of the rolling stock and reliable boarding/disembarking timescales, whilst enhancing the customer experience with a more comfortable journey. […]"
Tunnel Guide Lights to Assist Train Evacuation. "This system would add a further layer of assistance to make the evacuation process safer. The Crossrail central tunnels have a high-level walkway for workers and for passenger evacuation from a stranded or damaged train. These walkways have tunnel illumination luminaires at regular intervals above the walkway. This innovation proposes to mount, in each side of each luminaire recessed high-brightness LEDs such that they can only be seen when viewed end-on (i.e. when on the walkway). As a minimum these could be red and green (though there may be a use for a third color). Modern LED design would allow for these to be mounted in close proximity, simplifying design of the luminaire. They would be arranged such that they could be switched to red or green by the RCC (or left dark) whenever needed. […]"
Station Floor Navigation. "Provide color-coded lines with arrows (the same colors as the existing underground lines) on the floor for people to follow to navigate them to their onward journey. This could also be used to navigate people in a fire emergency by following an evacuation line on the floor. This will have the following benefits: reduce congestion and collisions; improve station safety; improve customer experience. The idea is often seen in airports and large Swedish megastores. Navigation around a new station can be confusing for people and there is always chaos at busy stations when tourists (bless them) spend a half a minute trying to decide which way to go at junctions and when alighting from a train. […]"
Knowledge Retention. "Implement a transitional handover – over a period of time – to allow for a seamless transition where knowledge generated in early activities (e.g. procurement) is retained/shared through to delivery and other future phases of the project. This could be applied equally to employers and contractors teams, thus ensuring that the delivery of the works recognizes the intentions of the employer derived during the planning and procurement phases. Behavioral/cultural changes that need to be addressed to allow for innovative thinking: There are failings in recognizing the lines of responsibility, and assumptions are based on previous experience rather than consulting current requirements - meaning effort is normally focused in the wrong place. […]"

Table 6. Successful Competition Awards by Project

Project	Awarded	Competition Round	Date
Connaught Tunnel	£11,500	Round 1	July 2013
Paddington	£1,500	Round 1	July 2013
Eastern Tunnels	£4,020	Round 1	July 2013
Paddington	£17,000	Round 1	July 2013
Paddington	£1,250	Delegated Authority	October 2013
Bond Street	£1,140	Delegated Authority	August 2013
Connaught Tunnel	£30,000	Round 2	February 2014
Liverpool Street	£15,000	Round 2	February 2014
Custom House	£10,000	Round 2	February 2014
Mile End	£10,000	Round 2	February 2014
Bond Street	£59,000	Round 2	February 2014
Tottenham Court Road	£18,000	Round 2	February 2014
Paddington	£10,000	Round 2	February 2014
Whitechapel	£10,000	Round 2	February 2014
Eastern Tunnels	£20,000	Round 2	February 2014

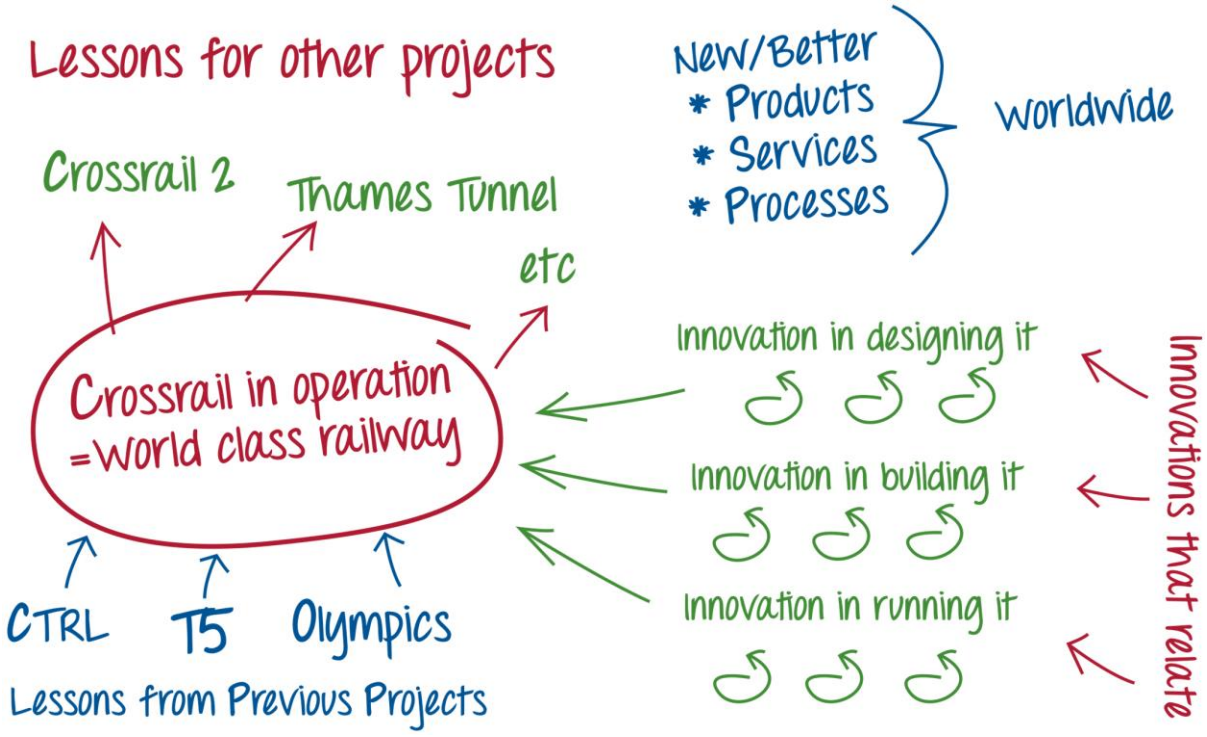

Figure 1. Crossrail Innovation Strategy

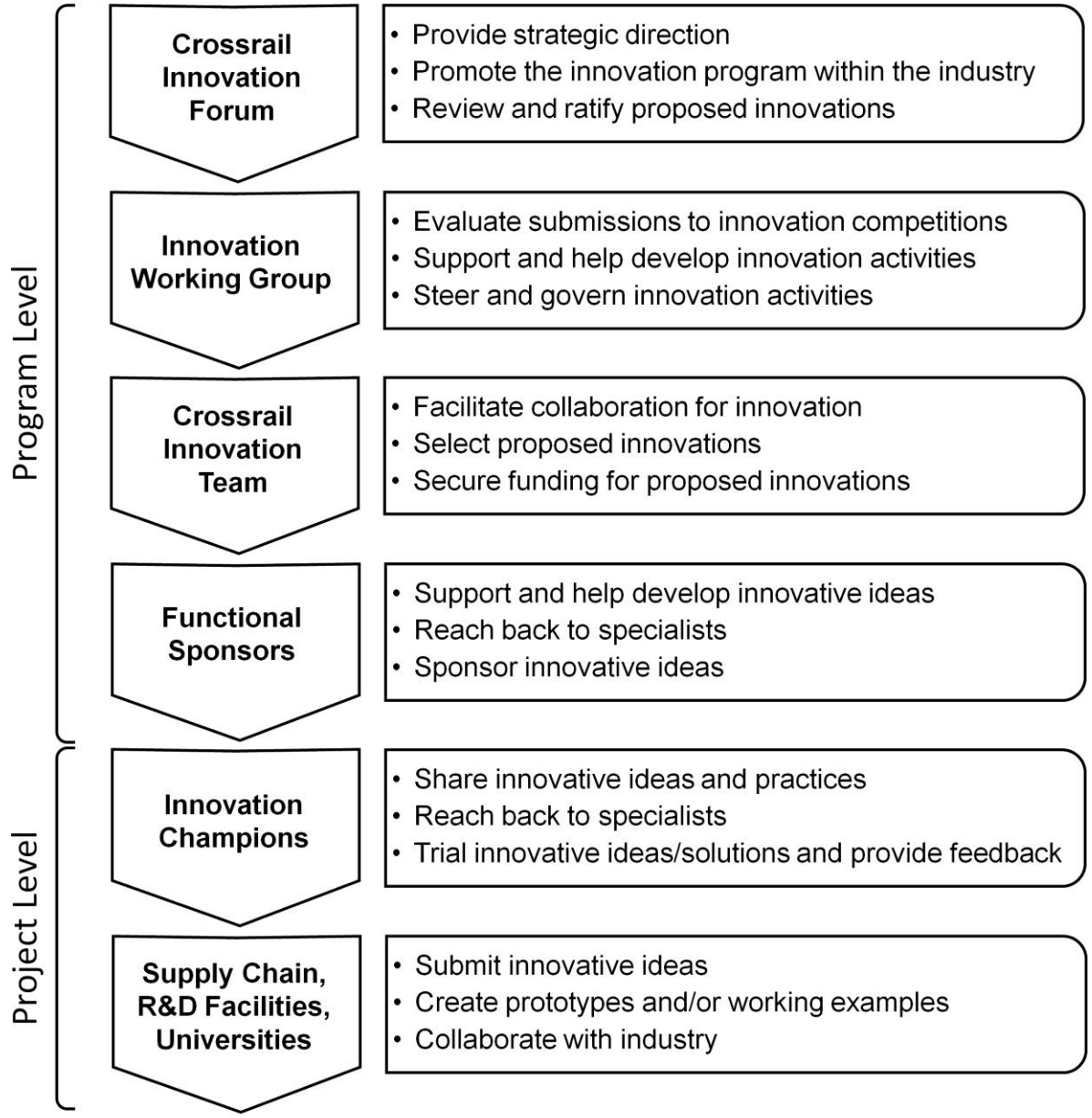

Figure 2. Organization of the Crossrail Innovation Program

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