

Design Boundary Dynamics in Infrastructure Projects: Issues of Resource Allocation, Path Dependency and Problem-solving

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Abstract

Due to their complexity and high social impact, urban infrastructure projects often face challenges in managing the design decision-making processes across disparate disciplinary and knowledge domain boundaries. This paper introduces the notion of *design boundary dynamics* to describe the various cross-boundary coordination phenomena associated with organising the design of infrastructure projects. Taking a practice-based theoretical stance, the paper presents findings of qualitative research on the nature and genesis of design boundaries and their relation to the strategic decision-making on a transportation infrastructure project. Findings illustrate the entangled processes, through which the disciplinary, knowledge-domain and stage-based design boundaries emerged as a result of unfolding project practices. Paper identifies the key role of resource allocation constraints, path dependency of project decisions, and problem-solving nature of design and concludes with strategic recommendations for upstream operational integration to mitigate the impact of design boundary dynamics on infrastructure projects.

Keywords: design management, boundary dynamics, projects-as-practice, infrastructure projects, case studies.

1 Introduction

There has been an increasing appreciation of the role that infrastructure projects play in the development of local and national economies. Very often, these infrastructure projects result in fixed assets whose main role is to facilitate the society as a whole to capture value from everyday economic and social activities. The complexity of the social and economic functions that infrastructure performs is also reflected in the organisation that delivers the project to the users. These complex organisations are sometimes referred to as complex project coalitions involving diverse user groups and communities that possess the power to determine the fate of a project, if they disagree with its goals (Morris 1994, Winch 2010). Because of the high social and economic impact coupled with very long life-cycles of infrastructure, decisions made in early stages of the project development pipeline will shape not only the physical outline and functionality of the asset but ultimately also the quality of the operations being delivered to the public by means of infrastructure (Brady and Davies 2010, Gil and Tether 2011). In a traditional project lifecycle context, these high-impact decisions are often attributed to the planning and design processes of infrastructure development. Despite the obvious importance of these knowledge-intensive decision-making processes, there is surprisingly little research that addresses design issues encountered in infrastructure projects (e.g., Gil and Baldwin 2014). Such design issues are often attributed to the various boundary phenomena that emerge across various knowledge domains in a typical infrastructure project coalition comprising diverse expert and stakeholder groups.

Previous research suggests that it is the role of project managers to facilitate project integration across internal and external boundaries of complex projects (Davies et al. 2009, Davies and Mackenzie 2014). Extant project research has also begun addressing some aspects of boundary phenomena in project organisations, for example the role of project

management in knowledge transfer across projects and the parent firm (e.g., Pemsel and Wiewiora 2013) or the role of boundary objects in mediating collaboration across knowledge domain boundaries within projects (e.g., Chang et al. 2013). Although existing research provides valuable insights on boundary practices in projects, it by and large takes for granted that boundaries exist as a structural feature of the project scope and its disciplinary knowledge features. Furthermore, existing research largely takes the positivist stance, in which project boundaries are understood as static, forming a structure that will stay in place throughout the project. At the same time, very little is known about the dynamic nature of internal boundary phenomena that emerge, change, and unfold over time as well as how they inform decision-making about courses of action to be taken (Langley et al. 2013). The aim of the study is to address this gap and better understand the challenges that occur due to knowledge interactions across disciplinary and knowledge domain boundaries on infrastructure projects. In other words, the purpose of the study is to tackle the *design boundary dynamics* as a key precursor of managing infrastructure projects. To this end, the study will adopt the stance that the internal boundary phenomena can be studied as they are made sense of by the practitioners who at the same time decide about different courses of action for the project. As a result, the study focuses on practitioners' perceptions as the primary figure of discourse.

The study specifically aims to address the following research question: *How can the genesis of design boundary dynamics in infrastructure projects be understood in the context of strategic decision-making?*

The focus on boundary dynamics is in stark contrast with most extant project research that conceptualises boundaries as a structural, and thus static, feature of project organisations. The value of such a contribution is aligned with the recent call for more research on social

interactions and practices in projects as opposed to a more traditional focus on project structures and performance (Floricel et al. 2014). Espousing the situational practices and their lived perceptions on behalf of the practitioners involved would also be a way to overcome the main shortcomings of traditional organisational research based on the paradigm of positivist rationality (Sandberg and Tsoukas 2011). To address this need, the paper will next draw upon research on design, work practices and sensemaking in the camps of organisational theory and project studies to derive a theoretical framework for the analysis that will follow.

The paper is structured as follows. The following section lays out a selection of design and practice-based studies in management and organisation research as well as the practice turn in project research as the basic theoretical framework for the inquiry. The paper then turns to boundary-related studies in the domain of mainstream organisation and project studies to elaborate the analytical level of analysis for this research. The paper continues with an exploratory study on the genesis of design boundary dynamics in infrastructure projects. This argument is developed through an analysis of exploratory interviews that expose how the selected highly-knowledgeable informants on the case project made sense of design boundary dynamics in project practices with the benefit of hindsight. After presenting the exploratory study, the main findings will be discussed by integrating conceptual ideas from design, boundary and practice theory to derive implications of the study for project practitioners. The paper will conclude with limitations and directions for future research in this area.

2 Making Sense of Design Practices

Research on design has a remarkably long and productive history of generating insights with broad-ranging interdisciplinary impact. For example, early design research has laid the groundwork for the seminal theoretical constructs now commonly referred to as *bounded*

rationality (Simon 1969/1996) as well as *reflective practice* (Schön 1984). More recently, design has been defined through the concepts of cognitive problem-framing leading up to the corresponding problem-solving activity (Dorst 2011). Drawing upon this body of design research, we can talk about design activity in practical terms as a combination of problem formulation, solving and decision-making practices leading up to distinct courses of action on projects (Zerjav et al. 2013).

The focus on micro-agency, problem-solving and decision-making activities makes design particularly conducive to practice-based theoretical interpretations. The origins of practice-based research in project studies can be traced to the so called *practice turn* in humanities and social research (Schatzki et al. 2001), a concept that has been extensively permeating the mainstream organisation and management research community in the last decade. The fundamental premise in this stream of theorising is that traditional strategy research has focused on the macro-level structures of organisations leading to concepts, which although might be plausible for management practitioners, they are highly-abstract and divorced from the level of activity that enacts the organisational reality (Whittington 2006, Jarzabkowski and Spee 2009). As a result, an increasing amount of research is focused on the discursive and material nature of day-to-day practices in organisations (Denis et al. 2007, Hardy and Thomas 2013).

Concurrently with the practice turn in strategy research, a similar development can be noticed in recent project studies. Origins of the practice-based project studies can be traced to the behavioural school of thought in early project management (Söderlund 2011), but only relatively recently has this movement gained prominence in the mainstream project literature. These studies, for example, argue that a focus on what people actually *do* in projects rather than what they *should do* would help in resolving the relevance issue, a shortcoming that has

often been attributed to the traditional positivist project management inquiry (Bresnen et al. 2005, Cicmil and Hodgson 2006, Cicmil et al. 2006, Smyth and Morris 2007, Blomquist et al. 2010). By drawing upon pragmatist philosophy, in particular John Dewey, researchers also began drafting some contours of pragmatist research into project practices as a form of applied science and explicating them through an epistemology of practice (Lalonde et al. 2010). Methodological implications of such an approach would thus point to grounded theory building, the use of in-depth case studies and ethnographies that capture significant episodes in which the practices meet both the practitioners and praxis (Blomquist et al. 2010). For example, Pitsis et al. (2003) analyse the day-to-day activities to understand the “future perfect strategy” of project delivery. Hällgren and Wilson (2008) use a study of fifteen critical events in construction companies to induce insights about the nature of crises and its management in projects. Along the same lines, Söderholm (2008) uses qualitative data from four case projects to induce strategies in which unexpected events are dealt with in projects. Besides qualitative multi-case studies, other methods were also used in the projects-as-practice tradition, for instance, metaphorical perspectives (Hällgren 2007) as well as in-depth ethnographic accounts (Sage and Dainty 2012).

The existing empirical coverage of the projects-as-practice tradition is mostly focused on typical emergent phenomena in projects, such as crises, power relations and the like, leaving the more common and mundane project practices relatively unexplored. This is particularly the case for managerial practices on design-intensive projects. Such projects need to coordinate disparate contributions of design as an entangled practice of both cognition and social interaction mediated by objects, models, and concepts (e.g., Ewenstein and Whyte 2009, Harty and Whyte 2009, Luck 2010). To advance the understanding of design boundary dynamics in project practices, the present study treats design as a specific *world of*

sociomaterial practices that become meaningful in the context of their respective goals, associated tools, as well as involved organisations and agents that make decisions and take actions (Sandberg and Tsoukas 2011).

Moreover, the analysis will adopt the angle of *sensemaking* as a process in which past actions are given meaning which, in turn, shapes the cognitive frames in which decisions are made about present and future actions (Weick et al. 2005). As such, the sensemaking angle acknowledges the interplay between the retrospective hindsight and informed future action in managerial decision-making (Winch and Maytorena 2009). Using the above-derived analytical framework this study aims to develop a practice-based explanatory account on design boundary dynamics in an infrastructure project using the interpretive angle of practitioners' sensemaking. Having espoused the conceptual framework for this study, I next present a selected body of studies that have dealt with different aspects of boundary phenomena in projects.

3 Boundary Research in Projects

A long-standing tradition of academic debate exists on the issue of organisational boundaries. The origin of this debate is often attributed to the Ronald Coase's article on the nature of the firm first published in 1937. This seminal paper begins theorising the dichotomy between the firm as an integrated economic entity as opposed to a number of economic transactions in the open market, an argument central to the discourse of transaction cost economics (Williamson 1985, Coase 1988). Since then, discussions on boundaries have significantly broadened beyond the traditional make-or-buy decisions to strategic and more fluent and emergent organisational demarcations. A literature meta-study by Santos and Eisenhardt (2005), for instance, comprehensively broadens the debate on organisational boundaries by

distinguishing between demarcations of efficiency, power, competence, and identity. Where *efficiency* as the most basic form of demarcation takes a legal ownership stance on the make-or-buy decisions, the demarcation of *power* is focused on the range of organisational influence, *competence* is focused on the resources available to conduct a certain scope of activity, and *identity* is focused on the mind sets that determine the organisational culture (Santos and Eisenhardt 2005). Boundaries, however, not only confine firms from their external environment, but they also play a key role in understanding how work is undertaken internally to organisations.

In idealistic settings, separate organisational units are assigned to non-separable chunks of work in the form of a one-to-one correspondence (e.g., Simon 2002, Thompson 2008/1967). Such an allocation of work then provides the theoretical basis for the organisational structure for the given effort. The pervasiveness of different kinds of boundaries is specifically studied in knowledge-intensive sectors an example of which is new product development and design. This is because knowledge tasks are interrelated and they spanning multiple units, which, will result in a number of boundary activities that can affect the performance of these organisations. Carlile (2002, 2004), for instance, described problematic knowledge boundaries that occur when working across different specialised domains in new product development. These boundaries are classified as syntactic, semantic and pragmatic and can arguably be crossed by processes of knowledge transfer, translation, and transformation (Carlile 2004). Building on these findings in the context of a *heterarchic* organisation with no clear hierarchical structure Kellogg et al. (2006), argue how boundary coordination is enacted in a “trading zone” through practices of knowledge display, representation, and assembly across community boundaries. In an even more recent study, Winch (2014) establishes a conceptual framework that distinguishes between the three different domains of project

organising: project-based firms, projects and programmes, and owners and operators. This study addresses the phenomenon of boundaries in a multi-actor perspective and at the same time introduces the dimension of temporality into the debate by defining projects as temporary configurations of permanent organisations.

Extant studies, therefore, identified the temporary and fluid nature of organisational boundaries that occur on complex projects. Boundaries are, for example, conceptualised either as interfaces between successive projects in an organisation (e.g., Julian 2008) or between different disciplinary teams within the project (Ratcheva 2009). Although extant studies are instructive, their important tenet is that boundaries are seen as a structural feature of project organisations, rather than as a phenomenon that emerges through practices and their post-hoc interpretations. In this paper I argue that adopting an interpretive view on boundary phenomena would be instrumental for informing project practices because of the multilevel nature of project-based organisations spanning projects, programmes, and portfolios, each requiring a substantially different organising mindset. Very few studies could be found that explicitly emphasise the fluid and socially constructed nature of boundaries in temporary organising. One example is the study by Drori et al. (2013), who analyse the negotiation of firm identities in the context of post-merger integration. This particular study approaches boundaries as a fluid and interpretive object of inquiry and calls for further research in this direction. In an attempt to respond to this call from a project organising perspective, the paper next presents the exploratory study focusing on design boundary dynamics in infrastructure project practices.

4 Research Setting

The empirical basis for this paper is qualitative research I conducted in the setting of a major transport infrastructure project. The case project involved extending a section of a rapid transit urban railway system and incorporating it into the suburban rail system of a major metropolitan area in the UK. The scope of work comprised the partial extension of tracks, the replacement of track and signalling equipment, and the construction and refurbishment of multiple stations. The overall project organisation included the public agency client and the contractor. The project was delivered in a design-build contractual arrangement, where the contractor was also responsible for the entire design effort of the project. Because the client's organisation did not have substantial experience in railway construction, they appointed a program management organisation to manage the project on their behalf. Concurrently, the contractor's organisation mobilised an engineering department for the project with the aim of coordinating design and construction. Due to the large scope of the effort, the contractor also appointed the "main designer" with the responsibility to provide the design deliverables to the contractor's engineering organisation. The project also had three major external stakeholders, being representatives of the urban and the suburban rail systems as well as the train operating company. The former two had the role of ensuring that the newly built section complied with the existing standards of both networks and the latter had the role to ensure that the delivered facility complied with their train operating procedures. Figure 1 illustrates the organisational structure of the project.

-----INSERT FIGURE 1 ABOUT HERE-----

4.1 Design Organisation

The structural nature of the design organisation of the project was a strong matrix. More specifically, design was organised in disciplinary work packages and geographic areas. The disciplinary work packages comprised civil design, structures, buildings and services, mechanical and electrical systems in buildings, and the accompanying rail technical systems. Each work package was further broken down into groups of geographically-adjacent tasks in the overall built structure. Given its scope, various parts of the overall design effort were distributed to a total of 22 different offices, which belonged to six different firms. To manage such a distributed effort, three specific coordination instruments were put in place: requirements management database, formal coordination meetings and stage-gate controlling mechanisms. The web-based requirements management database was established to distribute the requirements and change requests across the design organisation, as they would come in from either the client or as a consequence of the problem-solving process itself. The purpose of coordination meetings was to identify inconsistencies in the overall scope of design as well as to negotiate solutions that achieve tight integration between the technical components. These meetings were taking place regularly in the contractor's office where the responsible people from various disciplines would certify the current stage of development of design documents before the process could continue. Finally, the design process featured a stage gate controlling mechanism where an independent technical check was conducted to certify that the technical interfaces of different contributions were integrated and that the produced design complied with the requirements.

4.2 Design Process

The sequence of the design and construction tasks followed the areas of the railway section in a way that, as design tasks would take place for one area, construction works would have already commenced in the adjacent area, for which design had been previously finished and approved. Such a sequence is common in design-build arrangements as it allows for design and construction activities to occur simultaneously, albeit with a spatial and temporal delay in projects. The design process for a typical section would thus begin with the civil engineering design of the section, which was followed by the architectural design of the station buildings and, finally, mechanical and electrical design. In parallel to that, track design, signalling, and power systems design disciplines would be contributing to the design effort. It is clear that the interplay between the civil engineering design, architectural design and their relationship with the construction tasks generated a substantial need for coordination across the different activities. Moreover design tasks at hand were distributed to several organisations across both the civil engineering and architectural design domains. This was accomplished in a way that civil engineering tasks were assigned to multiple offices of the main designer's organisation due to the lack of capacity in the project local area. For similar reasons, architectural design tasks were distributed in the way that, for instance, four station buildings would have been assigned to a total of three offices whereby one office was assigned two buildings and the other two offices were assigned one building each.

The rationale for choosing this particular project as a case study was due to the size and complexity of the project requiring high levels of alignment and integration and, at the same time, a very fragmented design organisation that was producing the design. Following guidelines for case study research (Flyvbjerg 2006) the chosen project is a critical case of

unique circumstances in which emergent boundary coordination phenomena are extremely likely to occur.

5 Methods

5.1 Data Sampling and Collection

To collect the data for this study, I studied the case project working with the client's program management organisation, where I observed general working practices, studied internal and public project documentation, and extensively interviewed highly-knowledgeable informants. The aim of this endeavour was to identify the various boundary phenomena that emerged in the design coordination of the project and had an impact on project decision-making. To minimise my personal subjective bias, I entered the study with little prior familiarity with the specific phenomena that occurred on the project. The visit to the premises of the client's program management organisation took place in July 2010, at the time when the design processes were being finalised. This enabled me to acquire the informants' perceptions with the benefit of hindsight. The data collected comprises exploratory interviews, extensive project documentation, as well as publicly-available material about the project as is described in the following passage.

The process of data collection began with interviewing the project director who, upon my request, identified the informants with relevant knowledge about the key boundary coordination issues in design and their impact on project decisions. This approach yielded a total of seven informants who I chose as the basis for the in-field interviews. The interviews were semi-structured and open-ended, following ethnographic interviewing techniques (Spradley 1979). Apart from fixing the interview framework to emergent boundary and

coordination issues in project design practices, the interviews allowed a variety of topics to emerge naturally during the one-hour-long interview interactions with each informant.

Concurrently with the interviews, I also studied internal project documentation both as a continuing data validation effort as well as to gain a better understanding of the interviews conducted. The central source of internal project documentation was the main design management folder as part of the project file repository. At the time of my stay in the project offices, the design management folder contained 553 pages of various documents that I thoroughly studied during and after my stay in the field. Besides the design management folder, I also studied the documentation from the main project folder such as project reports, schedules, and organisational diagrams, which he deemed relevant for the analysis. Finally, I studied approximately 100 pages of publicly available material from press coverage of the project. Table 1 summarises the richness of research data collected on this project.

-----**INSERT TABLE 1 AROUND HERE**-----

During my entire stay in the project offices, the I engaged in comprehensive theoretical memoing of the insights as they occurred during the data collection session and interviews (Strauss and Corbin 1998). Thus, the analysis of data began in the field, through reflection and constant comparison of different sources of data. Upon leaving the office every day, I expanded and ordered the interview notes, combining them with other material collected on that day, which resulted in a comprehensive account of empirical data. After one week of extensive data collection and involvement with the informants, I concluded that the data was converging to the stage of saturation where significant new critical issues of boundary coordination phenomena were no longer being reported. As a result, I left the field and

continued the data analysis remotely. I then analysed the data by simultaneously consulting literature on boundary issues and their management in various types of organisations with the focus on projects. As the findings were emerging from the interviews, I conducted four additional telephone interviews with two informants for purposes of validation as well as to obtain additional insights about thematic areas that were emerging during the data analysis.

5.2 Data Analysis

To analyze the data gathered, I used the narrative-based theorising strategy with the aim to capture the rich contextual detail (“thick description”) of the design boundary issues that were unfolding on the project (Langley 1999). Because of the relatively ambiguous and eclectic nature of the data collected, the narrative strategy offered the advantage of reproducing the subtleties of the situations captured. The intention of using this approach is to not to claim broad generalizeability of the analysis, but to allow the readers to judge the transferability of the emergent findings to other situations through stories, meanings and mechanisms (Langley 1999). Following the narrative theorising strategy from the practice-based angle, I analysed the rich data at my disposal including interviews, research notes, internal project documentation, and publicly available accounts. The iterative data analysis involved re-reading, examination, and constant cross-comparison of the interview notes between the informants. In this effort, I used simple thematic coding to identify representative statements, recurring issues, and common terms (Strauss and Corbin 1998).

Along these lines, each individual interview was operationalised as a collection of key episodic events referring to cross-boundary coordination phenomena that informants encountered as part of project design practices. Because strategic episodes embody

organisational life as it is enacted in the lived experiences of its actors (Whittington 2006), these episodes were taken as the basis for further analysis. Following recommendations on practice-based theorising (Sandberg and Tsoukas 2011), I subsequently isolated three strategic episodes as illustrative examples of my analysis of emergent cross-boundary coordination phenomena on the project. These episodes are based on the informants' perceptions and understanding of unfolding design boundary dynamics in project practices.

I validated the strategic episodes capturing the emerging themes both internally and externally. Internal validation took place in the form of four telephone follow-up interviews with two key informants who not only further reinforced the emerging themes but they also provided additional detail about the design boundary dynamics in project practices. I conducted external validation by examining academic literature as well as trade press on common cross-boundary coordination issues encountered in other projects of similar scale and delivery arrangements as the project under study. This enabled me to establish correspondence between phenomena reported on other projects with ones being captured in the strategic episodes. By following this structure, I was able to articulate a coherent understanding of the empirical data and observations, which - as a result - also allowed me to better identify gaps in existing research on boundary design phenomena in infrastructure projects.

It is important to mention that the goal of data analysis was not to reconstruct an objective account on individual episodes and formally validate it across the informants, but to better understand how the design boundary dynamics is made sense of from the perspective of project practitioners and decision makers. This, in turn, would have permitted a generalisation of the findings not only in the context of infrastructure projects design but also

across a wide range of knowledge-intensive organisational practices. Having espoused the reasoning behind the data collection and analysis, I next present the findings of the study.

6 Findings

The present section presents the selected strategic episodes that illustrate different aspects of how emergent boundary issues were made sense of in the context of design (Whittington 2006, Blomquist et al. 2010). Following Sandberg and Tsoukas's (2011) advice on practice-oriented organisational research, I selected the episodes to illustrate the (1) overall organisational setting in which the phenomenon takes place, (2) the situational specificity of practitioners' lived experiences, as well as (3) the temporal dynamics of the phenomenon analysed. For purposes of narrative consistency, I will present the perspectives and quotes by two key informants of a similar level of seniority across the contractor's engineering and client's programme management organisations: the *Engineering Director (ED)* and *Infrastructure Delivery Manager (IDM)*. While the former was responsible for the integration of the design effort across the different organisational units, the latter's main role was to ensure integration at the design-construction interface of the project. I chose these two informants because of the level of detail they provided in their accounts throughout the series of two follow-up validation interviews each.

6.1 Episode #1: Disciplinary and Knowledge-domain Boundaries

The first strategic episode to be presented is selected as a description of the overall organisational setting in which the phenomenon under study takes place (Sandberg and Tsoukas 2011). In particular, the episode illustrates the organisational setting in which the contractor's engineering organisation undertook the role of coordinating the network of

offices that were assigned design tasks on the basis of the type of expertise needed. As a result, a number of groups working in disparate offices needed to collaborate on solutions for design problems at hand and handed them to the contractor's engineering organisation in the form of design documents. Since the physical components of the project needed to integrate well with both the rail infrastructure and with each other, the distributed network of design offices gave rise to a number of issues that were experienced from the project management perspective of the engineering organisation.

ED: Whilst the high-level stuff we got OK, once they started getting into the nitty-gritty details of how little bits and pieces tie together, we did have a lot of problems. We had to edit it and red light it and say: this doesn't fit here, this doesn't fit there and send it back to them.

One specific instance where the distributed organisational setting caused such issues was during the detailed architectural design of a railway station. As the different design offices were submitting their drawings of the same building, it was found that they used different selections of architectural fittings that were not possible to integrate in the given building. A similar example of this is when different offices used different types of expansion joints and different construction systems for the same elevated structure, causing issues in downstream phases of procurement and construction. All of these issues were caused by seemingly small differences in detailed design of the corresponding work packages, but were exacerbated by the need for seamless integration of the design task outputs. As a consequence, it was at the level of the contractor's engineering organisation that the need for cross-boundary coordination emerged. What obscured the emergence of these boundaries from the outset of

the project was the fact that a substantial part of the design effort was taking place beyond the realm of the engineering organisation.

IDM: Until that time, we were relying on [the main design organisation] to coordinate with all that offices, with other people, and to find out what the design subs were doing.

Aligning the design tasks across multiple detached organisational units and design groups was a challenge in its own right due to different locations of the people who needed to participate in the coordination meetings.

ED: Having [the designers] sitting in the same building and working together would have been helpful.

The complexity of the distributed network of design offices made it virtually impossible to predict the full range of emergent boundary phenomena that would have caused the need for additional coordination. Since coordination would have normally taken place only after a significant amount of work had been completed, rework was common. Up to three design iteration cycles were a common feature of this project as its result was a single integrated built structure designed in an interdisciplinary setting. Consequences of emergent boundaries finally materialised at the project management level as additional costs incurred through rework, travelling, delays, as well as other issues with downstream procurement and construction phases of the project.

ED: People had to travel long distances to meet up for meetings and you lose so much time in travelling.

After illustrating the overall organisational setting in which unforeseen boundary coordination emerged between different organisational units within the project, I next present an episode that illustrates emergent boundary coordination across project lifecycle stages.

6.2 Episode #2: Project Stage-based Boundaries

I next present an episode that refers to boundaries that were generated between design and construction project organisations. In terms of practice-based theorising (Sandberg and Tsoukas 2011), this episode is chosen to paint the picture of a specific situation in which the phenomenon of boundary emergence was observed. The situation refers to coordinating the interface between design and construction as a major effort in the fast track design-build arrangement that the project employed. The flow of design and construction was coordinated so that, as design would be completed for a particular section of the project, the documents would be transferred to the procurement and construction teams so that the respective section could be built subsequently. Nonetheless, due to the large scope of the project, the production of information at the overall level of design was not developing in a linear fashion, which caused alignment issues between the flows of design and construction. This was, for instance, the case in the situation where a station building was built without a sufficient allowance to accommodate the electrical systems.

IDM: They designed the buildings fairly early on and we'd had it built and then they would find that the switchgear didn't fit the room properly, or the cables were thicker

than they thought and more of them. So they had to drill some holes in precast walls and ceilings to allow for cables to pass through.

To illustrate the genesis of boundaries between design and construction in the above example, one should look at the flow of design that preceded the emergent coordination issue. Because design tasks preceded the construction activities by a relatively small temporal and spatial delay, construction was being informed by preliminary design knowledge. In particular, the station buildings were being designed – and subsequently built - with preliminary assumptions concerning the size of power systems, which they were supposed to accommodate. As the design proceeded towards the subsequent areas of the section, however, the input for design of electrical power systems was converging at values much higher than initially envisaged. Due to this increase, it was finally found that the stations, already built in the previous geographical area of the section, were not large enough to accommodate the equipment. When the issue was identified, it caused further delays in the planned flow of construction as the design would need to be amended to address the identified shortcomings.

IDM: Design cycles are different for different disciplines. They need their information at different times. At that time, the power systems designs weren't far ahead enough to know what the requirements on the buildings would be.

This situation also caused a substantial impact on the downstream construction organisation. The uncertainty in the requirements for the station buildings translated into the construction effort of retrofitting the station buildings to accommodate the power systems. Finally, this created constraints on the project procurement as only one producer could be found that was

able to offer the equipment that was sufficiently small in size. Finally, the synchronisation issues between the design contributions caused delays in the design approval processes and threatened the project with serious delays.

ED: Just to get things going on the site, we had to cut across some of the formal procedures from programme management. Design was simply taking too long to get approved. If we would assess the risk to be acceptable, we would go out and build it at our own risk.

After presenting the episodes that illustrate the main types of boundaries that emerged during project design, I will next turn to the process in which boundaries were unfolding. The aim of this perspective is complete the picture on design boundary dynamics in infrastructure project practices as opposed to boundaries understood as a structural and static feature of project organisations.

6.3 The Emergence of Design Boundaries

The third episode is selected to address the temporal aspects of practice-based theorising (Sandberg and Tsoukas 2011) focusing on the process in which the boundaries emerged and unfolded on the project. This episode describes a situation that was triggered by the client introducing an “on the fly” design change request to provide a possibility for an external escalator for a particular station building. This requirement was subsequently handed over to the contractor’s engineering organisation that was in the project management role for the design effort.

In boundary terms, the client's requirement entered the realm of the engineering organisation. As the requirement was communicated to the engineering organisation, it became obvious that the current state of design had not provided sufficient power allowance for the external escalators and that additional power was needed for the provision of this escalator. This triggered an emergent task in the power systems design domain. By moving into the domain of power systems design, the design activity to address the client's requirement crossed another domain boundary. As a response, power systems experts began upgrading their design solutions to provide sufficient capacity that would address the requirement introduced. However, as the power system designers were working on their tasks, it was concluded that, in order to provide the necessary power supply, more space in the station building would have been necessary to accommodate the placement of the new power system resulting from the requirement.

This, in turn, caused the design activity to migrate to the domain of building design, crossing its third boundary in this process. It is within the boundaries of this discipline that a team of dedicated experts was working out solutions to provide additional space in the station to accommodate the equipment needed for the escalator. During the activity in the domain of building design, however, it was discovered that, to provide for the additional space in the building, additional land had to be acquired and a new planning permission obtained. This caused the design activity to cross its fourth boundary in the process of working out solutions that would have addressed the initial client's requirement.

As a result, design practices migrated into the domain of planning and land acquisition with the aim to both acquire additional land and obtain the necessary permits for the upgrades onto the originally designed structure. One of the consequences of the process of obtaining the

permit for the introduced design changes was a request to the local electric utility to increase the amount power delivered to the station. The design activity, therefore, crossed its fifth boundary in the process of responding to the requirement. In this case, however, the planning and land acquisition group found that the costs of acquiring the additional land and the time that the corresponding procurement and legal procedures would have taken up, would have a major adverse impact on the project success. As a result, the engineering organisation concluded that the initial requirement for the passive position of an external escalator should be abolished.

ED: ...this made an enormous difference because the local power supplier wasn't able to provide enough power for those two escalators. To do that, [the client] would have had to spend an immense amount of money, far in excess of anything that he had envisaged.

-----**INSERT FIGURE 2 AROUND HERE**-----

Figure 2 illustrates that the initial requirement caused a substantial impact on the overall project through the mechanism of successive activity transformations across separate domains. While the original requirement triggered first, second, and third order activity by permeating into the domains of power systems, building design, and planning, the activity was stopped with the requirement hitting the “hard” boundary in the electric utility domain. The described chain of activities across boundaries corresponds to the interdependence between the disparate contributions where, as a result of a change introduced in one task, a

number of other tasks needed adjustments. The main point of this episode can be illustrated with the following quote.

ED: These things can have all sorts of little strings that are going to go all over the place. And it's just one of those things that happen. You're working through a particular issue and all of the sudden you find that it is going to cause a horrendous situation.

After describing the genesis of design boundary dynamics using selected strategic episodes to address the relevant aspects of practice-based theorising, I next discuss the findings in the light of the research question. To this end, I will next discuss the findings and their implications to address the extent of their theoretical generalisability and their value for managerial practices.

7 Discussion: Issues of Resource Allocation, Path Dependency, and Problem-solving

The aim of the study was to understand the genesis of design boundary dynamics in infrastructure projects in the context of strategic decision-making. Findings illustrate the disciplinary and knowledge-domain boundaries between different organisational units, project stage-based boundaries at the interface between design and construction and a subtle and entangled process in which design boundaries emerged as a result of unfolding project practices.

A second-order analysis of the findings informed by literature on boundary-related organisational research (Gioia et al. 2013) suggests that the genesis of design boundary

dynamics in infrastructure design can be attributed to *(1) resource allocation constraints, (2) path dependency of the decisions in the design processes* and *(3) problem-solving nature of the design activity*. I next elaborate these aspects in more details.

Firstly, the disciplinary and knowledge-domain boundaries described can be understood as a consequence of cross-unit allocation of resources. More specifically, resource allocation was subject to constraints due to the scale of the project combined with the market demand of expertise that did not allow the main designer to source the project from the local offices. This can also be seen as an example of a project externality that had an impact on internal resource allocation decisions. Secondly, the stage-based boundaries described in the second strategic episode can be seen as a path dependency issue enacted at the micro-level of design decision-making. To be more specific, the trajectory of past design decisions was such that it was not only limiting the scope but also colliding with present and future decisions, thereby creating stage-based design boundaries. Finally, the third strategic episode can be seen as an example of iterative and problem-solving nature of design in which the initial design activity was transformed into a series of higher-order activities that, in turn, expanded the initial scope of the effort, and as a result needed to be rejected.

Having identified the impact of resource allocation, path dependency, and problem-solving features of design, I would next like to introduce strategic recommendations for project management practitioners. The aim of these strategic recommendations is to achieve upstream operational integration with the potential to mitigate the potentially adverse impact of design boundary dynamics on infrastructure projects.

To start with, it should be mentioned that experienced and creative project managers can come up with any number of alternative resource allocation and collaborative problem solving strategies for their projects. The purpose of this section is therefore to address some of the enabling conditions for alternative resource allocation and collaborative problem solving strategies.

Firstly, project managers can encourage long-term collaborative arrangements in the form of strategic alliances, in which alternative resource allocation strategies are possible. In such arrangements, specialist project expertise can be developed within a common pool of resources. On the one hand, the investment in developing the common pool of resources can be seen as increasing the risk of lock-in and opportunistic behaviour by individual parties. On the other hand, the same investment creates the necessary conditions for the individual parties to leverage the benefits of learning and trust that can be used as a strategic asset over a pipeline of future projects. Working in strategic alliances over a series of projects enables managers to increase the scope of their resource allocation decisions without having to rely on volatile conditions of market supply and outsource project expertise on a one-off basis. In the case project, for example, the operational structure of the design organisation, was more akin to a market purchasing arrangement as opposed to a strategic alliance. As individual offices were contributing to the design as stand-alone units, not much scope was left for coordinating the production of design at the operational level.

The second strategy for achieving upstream integration refers to collaborative problem-solving. Although it is clear that it makes little sense to be prescriptive about collaborative behaviour as it only happens when it is voluntary and self-initiated, it also seems clear that trust between the parties is a necessary condition for the emergence of collaboration.

Following this line of reasoning, managers can promote relational contracts between the client and the main suppliers, creating incentives for collaboration in the so-called integrated project team arrangement. In such a setting, the client takes on the risk for the entire project, unlocking opportunities for collaborative working relationships across the value chain and arguably alleviating a number of issues caused by adversarial and competitive behaviours that stifle collaborative problem-solving.

Although it is evident that implementing the above strategies is not a decision that project managers can make single-handedly, there appears to be a strong argument for upstream operational integration in infrastructure projects. Project managers can use this argument with clients and suppliers to create conditions for effective collaborative design and better performing infrastructure projects as a result.

While the nature of findings presented in the paper is fairly conceptual and descriptive, it can be argued that a sensemaking perspective on design boundary dynamics in infrastructure project practices is generalisable on the basis that it illustrates a common phenomenon (Flyvbjerg 2006) that exists on a myriad of infrastructure projects, of which the illustrated case might be seen as a typical example. More specifically, this suggests that the practices in the case project might have a bearing for a class of projects similar in complexity and scope to the one analysed in this study.

8 Contributions, Limitations, and Future Directions

The findings contribute to the wider debate that acknowledges the lack of research on infrastructure design (e.g., Gil and Baldwin 2014) as an organisation that operates in a complex interplay of infrastructure delivery coalitions and diverse user groups and

communities (Morris 1994, Winch 2010). As such, the findings extend the existing body of project boundary research through an understanding of boundaries as an interpretive and enacted phenomenon, in contrast to boundaries as a structural feature of project organisations (Kellogg et al. 2006, Julian 2008, Ratcheva 2009, Pemsel and Wiewiora 2013, Winch 2014). More broadly, the present study enriches the body of research on social interactions, practices and sensemaking in organisations and projects (Weick et al. 2005, Smyth and Morris 2007, Winch and Maytorena 2009, Sandberg and Tsoukas 2011, Floricel et al. 2014) with an account on unfolding boundary design practices, a topic that has thus far only been under scrutiny from the perspective of project structures and performance as opposed to practitioners' sensemaking.

Lastly, the main practical contribution of the study is that project leadership on infrastructure projects can achieve upstream operational integration by devising strategies of alternative resource allocation and collaborative problem-solving to mitigate the potentially adverse impact of design boundary dynamics that are likely to occur on infrastructure projects.

As any research, this study has its limitations, which should be here acknowledged. The claimed theoretical and practical relevance of this study hinges upon several methodological assumptions that might require further clarification. This includes, in particular, the use of a single case study and strategic episodes to derive narratives that illustrate the argument of the paper. First of all, I contend that relying on context-dependent data from such a limited snapshot of a large project does not lend itself to large-scale statistical generalisation of the findings. However, it was not the intention of the paper to reveal the full complexity of boundary design phenomena and practices. It was rather to begin an exploration and ultimately indicate some of the mechanisms through which design boundary dynamics is

generated and understood in terms of its impact on the performance of projects and corresponding decisions. This topic was not taken into account in previous research and the study suggests this notion possesses substantial explanatory value for both future research and organisational practices in project-based businesses. All this indicates that the nature of theory presented in this paper is mostly descriptive with the main aim to provoke not only new hypotheses to be tested by future research but also novel ideas to be implemented in managerial practices and policy (Flyvbjerg 2006, Siggelkow 2007). Most importantly, however, I believe that the practice-based sensemaking stance that was adopted in this research has the potential to alleviate the tensions between the mainstream method-based research that emphasises normative managerial action - on the one hand - and the critical project studies that call for rich descriptive research of emergent phenomena due to complexity and multiplicity of project realities – on the other (Bresnen et al. 2005, Cicmil and Hodgson 2006, Smyth and Morris 2007).

Finally, since the analysis presented in this paper is reasonably conceptual, the findings call for further follow-up empirical treatment. This could be achieved through a longitudinal grounded study encompassing several projects that would, at the same time, provide richer insights on design boundary dynamics and allow for a greater level of generalisation of the findings. Another potentially fruitful area for future study would be the boundary crossing role of objects and artefacts allowing different communities of practice to work across their domains. More generally though, there is great potential in using an interpretive approach for future studies as the goal of the stream of research this study belongs to should be to better understand and advance the cognitive infrastructure of managerial decision-making rather than to seek straightforward optimisation of organisational processes.

9. Acknowledgments

Parts of the interpretive qualitative study have already been presented in different forms in other papers by the author, however, from different theoretical angles, which led to substantially different contributions. I would, furthermore, like to express my sincere gratitude to the informants of the study who all chose not to disclose their details. In particular, I would like to thank the engineering director and the project director without whom this study would have been impossible. Secondly, I would like to thank Timo Hartmann for the discussions that contributed to the development of early ideas which led to the present paper. Finally, I am grateful to my colleagues Andy Davies, Andrew Edkins, John Kelsey, Effie Konstantinou, Stefano Miraglia, Beth Morgan, Peter Morris, Kamran Razmdoost, Natalya Sergeeva, and Yiming Wang who helped me further refine and sharpen the argument presented in the present article. Finally, I gratefully acknowledge the four anonymous reviewers who helped me sharpen the manuscript for publication. All errors and omissions, nonetheless, remain my sole responsibility.

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Figure 1 - The structure of design organisation in the case project

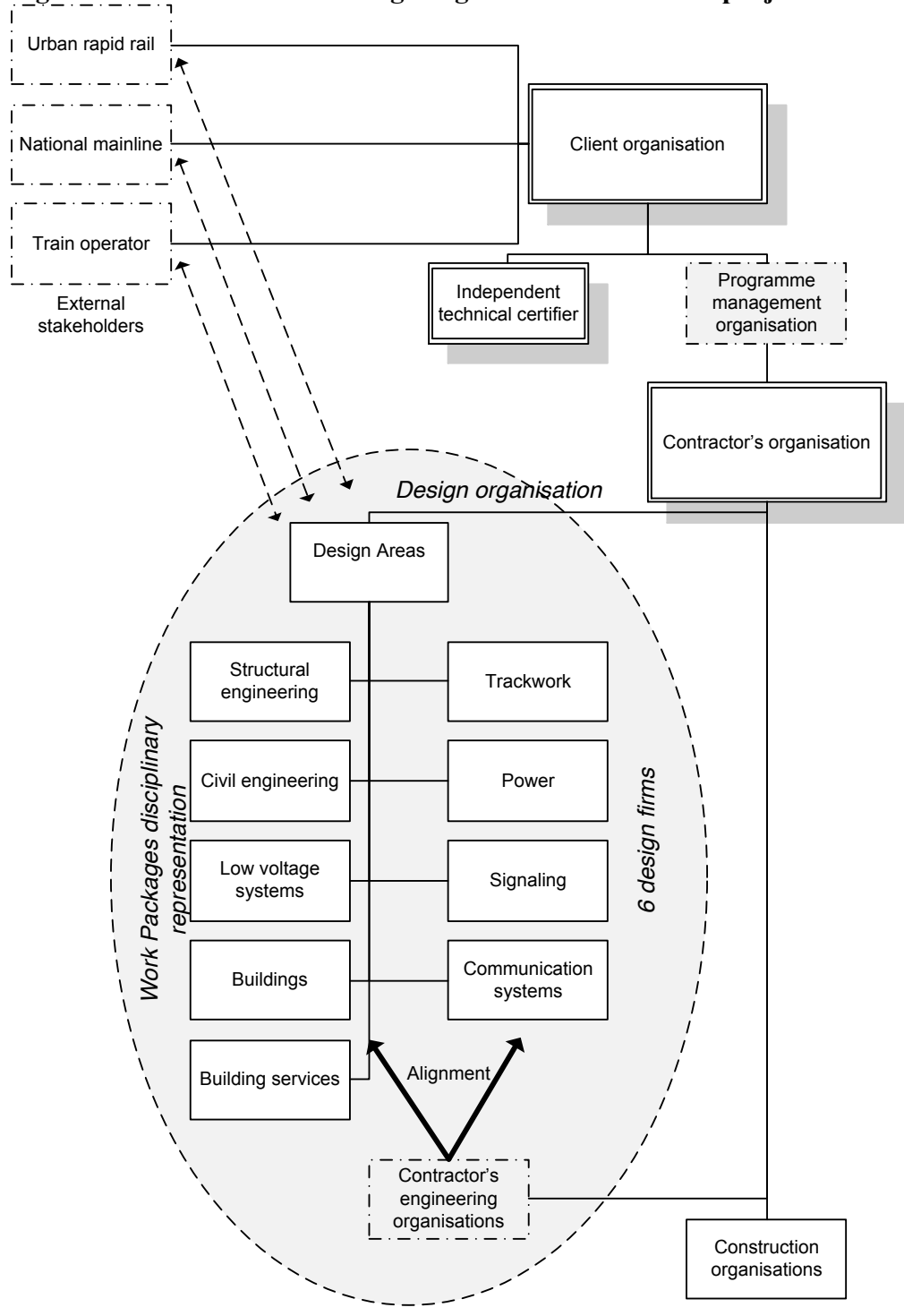


Table 1 - Summary of data sources for the research

<i>1. Highly-knowledgeable informants</i>	<i>Position held</i>	<i>Organization</i>	<i>Total sessions conducted</i>
Informant #1	Program Director	Program Management	3 interview sessions
Informant #2	Engineering Director	Contractor	3 interview sessions
Informant #3	Infrastructure Delivery Manager	Program Management	3 interview sessions
<i>2. Other informants</i>	<i>Position held</i>	<i>Organization</i>	<i>Total sessions conducted</i>
Informant #4	Office leader	Program Management	Ongoing daily interaction
Informant #5	Control Systems Delivery Manager	Program Management	1 interview session
Informant #6	Junior Engineer	Program Management	1 interview session
Informant #7	Project Director	Client	1 interview session
<i>3. Other data</i>	<i>Description</i>	<i>Source</i>	<i>Amount of data</i>
Design Management Folder	Procedures, reports, schedules, communication, organization charts, etc.	Internal database	553 pages of documentation
Media coverage	Press coverage, TV featured programs, etc.	Publicly available	Approx. 100 pages

Figure 2: The process of design boundary emergence

