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**Designing for Complexity:
Data Visualizations in Megaproject Management**

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Doctor of Philosophy
The University of Edinburgh
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Declaration

This is to certify that the work contained within has been composed by me and is entirely my own work. No part of this thesis has been submitted for any other degree or professional qualification.

Signed:

Matteo Ronzani

Abstract

Focusing on the format of dashboards and the visualisations of performance indicators, this thesis explores the design features that make accounting visualisations influential in shaping the management of highly complex and dynamic organisational settings. Informed by empirical research on the reporting design practices in Crossrail, Europe's largest infrastructure megaproject, this thesis theorises how the design of data visualisations is consequential in supporting engagement with the challenges of project delivery and how they enable and constrain interaction. To address these concerns, this thesis develops a comprehensive design framework for the study of the visual in accounting. It does so by drawing from the design theory concepts of affordances, visual and aesthetics literacy, and visual conventions to investigate how designers deploy specific forms and features to pre-form practices of future interaction with visual artefacts. Theorising five interrelated design principles – multimodal balance, visual relationality, optical consistency, functional beauty, and the emphasis on incompleteness and the visualisation of consequences – this study makes three contributions to the study of the visual in interdisciplinary accounting. The first contribution informs the accounting literature on the design of accounting visualisations unpacking how designers visualise the multiplicity and interconnectedness of complex organisational phenomena and theorises how such artefacts can support the creation associations to tackle complexity and emergence. The second contribution is to the literature on numerical pictures in accounting and relates to how aesthetic attributes can augment the power and interactional possibilities of visualisations. The third contribution of this study consists in the fact that it offers a design perspective to the study of the visual in accounting. In fact, this thesis investigates how reporting designers construct visualisations and does so relying on a theoretical framework developed based on notions borrowed from design theory.

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1. INTRODUCTION

We need a thoughtful medium in which the qualities of particular situation can be represented (Arnheim, 1991, p. 184).

In the world of project managers, accountants and engineers involved in the management of megaprojects, dashboards and other visual representations of performance and delivery information are foundational components of communications and interactions. In such settings, data visualisations are so pervasive in the way people think about and deal with problems that coordination, conflict, negotiations, and decision take place over, on, and through them. These visual artefacts are implicated in the shaping of the structure of the work and the interactions in the workplace. In this sense, they represent a fundamental articulation of social organisation developed on the basis of collective ways of knowing related to the design, construction, interpretation, and practice of visual artefacts. Although it is undisputed that artefacts have agency and politics, much less is known about how the people who design and construct data visualisation envision their configuration, interactional possibilities, and practices of future use. More specifically, the reporting designers' activity of conceiving and constructing dashboards and other purposeful visualisations remains mostly under-investigated in accounting research.

Given the pervasiveness of these material artefacts in the visual culture of megaproject organisations (see Henderson, 1999; Ferguson, 1999), the study of how these reports are designed and why they are designed in specific ways offers significant potentialities for development. Despite a number of recent calls for research to further explore the visual nature of accounting numbers (Qu & Cooper, 2011; Quattrone et al., 2013), the practical construction of performance measurement technologies and their visualisation (Dambrin & Robson, 2011; Busco & Quattrone, 2015), and on the roles of aesthetics and functionality in the design of visual artefacts (Espeland &

Stevens, 2008; Pollock & D'Adderio, 2012), the design of accounting visualisations remains an under-explored research area.

We are currently living the sociological experience of a society increasingly pervaded by images, visualisations, charts and matrixes, and accounting research in the last twenty years has meaningfully reflected the interest on visual media in the study of its technologies, practices, and social and organisational consequences. Visual research in accounting configured itself as an innovative area of study, inspired by methodological eclecticism and willingness to explore the epistemological and thematic boundaries of the discipline, relying on a variety of theoretical perspectives (Davison, 2015). The focus of this research stream has however been mostly centred on the analysis of the communicative, narrative, and persuasive features of pictures and images related to accounting (e.g., Graves et al., 1996; Davison, 2011). This stream of studies explored the representational, ideological, and rhetorical roles of pictures in annual reports (Preston et al., 1996; Preston & Young, 2000). In so doing, they unpacked how the visual dimension of reports for financial disclosure systematically encode intellectual, symbolic and social intangibles that are functional in supporting the truth claims they contain (Davison, 2010). These studies have shown how visualisations, disguising themselves as information rather than argument, perform a variety of persuasive and manipulative roles towards their audiences. Building on these insights, a different stream of studies moved beyond the concern with pictures and explored how the visual and aesthetic features of accounting technologies as such were fundamental in their popularisation and widespread practice (e.g., Thompson, 1998; Suzuki, 2003b). While these works offered important insights, they did not tackle how the visual design of accounting technology influences practices of future use, beyond their rhetorical role.

These concerns are paramount for accounting research. In fact, not only visualisations have essential framing effects (Tversky & Kahneman, 1986), but also visual material can attract a disproportionate amount of attention and time in analysis and evaluation

(Tversky, 1974). A series of experimental accounting studies have also corroborated the importance of the visual organisation of information on decision-making and performance evaluation. Not only graphical formats can improve the accuracy of forecast judgments (Desanctis & Jarvenpaa, 1989), but different modes of presentation of information can be tailored to cater for the specific information needs of individuals with different levels of accounting knowledge (Cardinaels, 2008). Additionally, research has shown that the visual organisation of management accounting technologies such as the Balanced Scorecard can be altered to systematically increase the weight evaluators assign to non-financial indicators (Lipe & Salterio, 2002). Although these mainstream studies highlight the influence of the visual features accounting technologies in framing performance evaluation, they do not explore how specific visual design features engage the users in a transformative capacity and do not address how such technologies unfold in practice.

Accounting technologies that rely on the visual medium may unfold through use in novel and transformative ways and can support engagement with the incompleteness and ambiguity that define complex organisational settings. A series of interdisciplinary studies theorised on the importance of “the graphic *format and furniture*” (Pollock & D’Adderio, 2012, p. 581) of accounting technologies, showed how visualisations can offer a method for the organisation of thinking and knowledge (Quattrone, 2009), and facilitate framing, create order, and limit externalities (Cooper et al., 2017). This stream of studies also explored how the features of such technologies can engage the users in repeated accounting performances (Qu & Cooper, 2011), mediate between predictability and control, recombination and difference (Busco & Quattrone, 2015), and can act as engines for reflection and innovation (Revellino & Mouritsen, 2015).

Taken together, this stream of research theorised how specific visual technologies could play a variety of constitutive roles that go beyond representation, such as territorialisation and mediation (see Miller & Power, 2013). Specifically, they linked these generative effects to precise properties of visual artefacts, such as their simplicity

(Pollock & Campagnolo, 2015), mediating and constitutive capacity (Pollock & D'Adderio, 2012), and interdiscursive appeal (Jordan et al., 2016). Despite these significant contributions, little is known about the design features that pre-form and influence interactions and on the criteria according to which designers construct such visual artefacts. In this sense, very few studies “have provided insight into the makeup and minutiae” (Pollock & D'Adderio, 2012, p. 581) of the design of accounting visualisations and “the problems of their practical construction” (Dambrin & Robson, 2011, p. 430).

Instead of studying how established accounting technologies unfold in practice, this thesis explores the design of data visualisations in the management of a megaproject. Focusing on dashboard design and the visual format of performance indicators, this thesis explores how reporting designers convey interactional possibilities to the artefacts they construct to shape managerial decisions. In so doing, this thesis offers a design perspective on the study of the visual in accounting. Here, the meaning of ‘design perspective’ is twofold: This thesis is both articulated theoretically through the development of a framework based on design theory, and its empirical focus lies on how reporting designers construct visual artefacts to support the delivery of a megaproject. This study makes a case for the potential of design research to inform accounting scholarship.

Design theory has a long tradition and is linked to different disciplines, including engineering, the social sciences, the humanities, and philosophy. According to Herbert A. Simon (1996), at the highest level of generality, design is about the devising of courses of action to deliberately change existing conditions into preferred ones, with a focus on artefacts, interfaces, and assemblies of actions. In achieving this goal, the design discipline is concerned with the creation of artefacts within a tradition of practice (Murray, 2012), investigating what enables interaction, attracts attention, and engages users (Ware, 2012). In this sense, a series of research areas under the umbrella term of ‘design research’ – such as human-computer interaction, data visualisation,

and interaction design – can offer valuable and innovative insights in the study of accounting. To tackle these issues, this thesis proposes a comprehensive framework for the study of visualisations that establishes an epistemology of design that links design concerns with the ontological and cultural status of technologies of visualisations. This framework is based on the interrelation of the design notions of affordances (Norman, 2013), visual and aesthetic literacy (Messaris & Moriarty, 2005), and visual conventions (Kostelnick & Hassett, 2003).

Affordances are interaction possibilities latent in the design of objects that shape what an artefact is for and which actions are possible. Accordingly, affordances induce but do not determine decision outcomes (Hutchby, 2001), thereby highlighting how designers can pre-form interactions while leaving the question on the final goal of an action interpretively ambiguous (Stark & Paravel, 2008). Given their interactional nature, affordances have a potential mode of being that helps to understand the possibilities and limitations of visualisations, as well as their enabling and constraining effects. The potential mode of being of affordances makes their identification partly dependent conventional factors that characterise a culture, community, profession or organisation (Espeland & Stevens, 2008), along with factors that relate to the competencies and features of the interacting subject (Ewenstein & Whyte, 2007). Hence, the design activity of ensuring that an artefact offers the hoped-for interactional possibilities goes beyond the functional design specifications of the artefact in question (Gaver, 1991).

To engage meaningfully with a visual artefact, interactors need to be visually literate. Visual literacy is the interactor's awareness and knowledge of how visual artefacts are created, understood, and practised in a setting (Messaris & Moriarty, 2005). Visual literacy, as the ability to understand 'visual statements' (Kress, 2009), is an essential pragmatic competence that relates to thinking, learning, and expressing themselves in terms of images and visualisations (Henderson, 1999) as well as appreciating and capitalising on their aesthetic properties (Stigliani & Ravasi, 2018). The theoretical

exploration of visual literacy and aesthetic knowledge enables to investigate in depth the trade-offs between aesthetics and functionality in the design of visual artefacts and sheds light on some of the core preconditions to make visualisations influential in shaping interaction. In the light of these considerations, another element that emerged as central in the design and practice of accounting visualisation is the importance of their conventional design features (Ware, 2012). Visual conventions are concerned with the visual language deployed by designers in the creation of organisational artefacts (Kostelnick & Hassett, 2003). The analysis of the visual conventions in design processes shows how a visual language can normalise visual practices among designers and users, while at the same time creating the preconditions for innovation and recombination of visual features and their interpretations. In this sense, it enables precise analysis of the rhetorical features and functions embedded in dashboards and reporting products.

Combined, the notions of affordances, visual literacy, and visual conventions offer a comprehensive set of lenses to explore, at different levels of analysis, the enabling and constraining properties of visualisations and the language used by designers in their construction. The epistemology of design proposed in this thesis is discussed in the light of the notion of sociomateriality (see Orlikowski, 1992, 2007; Bjørn & Østerlund, 2014). Not only sociomateriality moves beyond privileging either the material or the social in the study of technologies and artefacts but also a common feature that runs through the proposed theorisation is a concern with the exploration of how design features generate non-deterministic processes of constrained opportunities (Stark & Paravel, 2008). Specifically, the design notions at the core of the proposed theorisation are concerned with the possibility of designing artefacts without predefined boundaries that, thanks to their interpretive flexibility, can both be malleable and dynamic while remaining the same. In this sense, design research concerns are linked to the sociomaterial relational ontology to explore the design and operation of visual artefacts in megaproject management.

To explore the research concerns of this study, a qualitative case study approach was selected as the appropriate method to offer a nuanced examination of the design and practice of accounting visualisations (Czarniawska, 2014). The methodology section builds on literature that has problematized how it is possible to learn from case studies (i.e., Flyvbjerg, 2006; Quattrone, 2006; Barzelay, 2007) and, drawing from Agamben's (2009) notion of 'paradigmatic case', explores the status of knowledge acquired through case studies and links these concerns with issues of case selection. Specifically, the methodology section aims to offer an innovative justification of the validity of qualitative case studies, showing how cases can grant stable ground for social scientific enquiry by overcoming the issue of context-specific knowledge as opposed to generalizable knowledge. In so doing, it discusses how paradigmatic cases, working analogically from singularity to singularity, present a canon that cannot be shown in any other way and generate knowledge insofar as they are irreducible to universals (see Agamben, 2009).

In line with this approach, this thesis provides a detailed empirical study of management control and reporting visualisations in Crossrail, Europe's largest infrastructure megaproject. Crossrail is the delivery vehicle for the construction of the Elizabeth Line, the new high-frequency, high-capacity railway for London. With £15 billion funding and 14,000 people employed at peak, Crossrail is an ambitious and complex infrastructure megaproject that is on time and budget (NAO, 2014; Marrs, 2016), and this makes it a notable exception in an industry characterised by a poor track record in terms of performance and benefits realisation (see Flyvbjerg, 2007, 2014). Crossrail's management is characterised by a shared belief in the importance of data visualisations in stimulating reflection and supporting engagement with accounting information, and this had a significant impact on the design of reporting products in the Programme Controls department, which will be investigated in depth in the findings chapter.

Megaprojects such as Crossrail are ideal settings to investigate how accounting and management control visualisations become performable and support decision-making (see Whyte et al., 2007; Quattrone, 2017; Thomsen & Skærbæk, 2018). That is because such projects are paradigmatic examples of complex settings since they are characterised by widespread misinformation about costs, benefits and risk, have long planning and delivery horizons, and employ non-standard technologies and complex interfaces (Flyvbjerg, 2007). Additionally, such settings are characterised by emergence, where answers are likely to evolve from circumstances and not from preconfigured solutions, and this is connected to the fact that, as temporary project structures, megaprojects have an interconnected and always-unfolding ontology (see Nocker, 2006; Hodgson & Cicimil, 2006). In the light of these features, megaprojects are sites of great social, technical and political significance and, according to Hirschman (1995, p. vii), they represent “privileged particles of the development process” that are ‘trait making’ in shaping the future of societies. Despite their technical interest and social implications, accounting issues in megaproject management are an under-researched area of study. In this context, Anthony Hopwood’s (2005, p. 856) contention that “the operation of accounting in temporary project structures has not been researched extensively” is now even more relevant than before, given the increasing importance of megaprojects on a global scale (Flyvbjerg, 2014). Accordingly, the exploration of design principles to visualise information is especially valuable in organisations characterised by high levels of complexity, dynamic change, and emergence such as megaprojects.

1.1. Research questions

This thesis explores the design and practice of data visualisations in the management of a megaproject. It aims to shed light on the principles and criteria that make visual artefacts, such as project dashboards and KPIs visualisations, influential in supporting engagement with complex settings. Accordingly, three research questions are proposed:

Research question 1: What kind of interactions can data visualisations generate in the delivery of megaprojects?

This first overarching question provides the direction of the overall investigation. It focuses on the roles that the design and practice of data visualisations and their affordances can play in supporting the engagement with complex and always-unfolding phenomena, such as the delivery of infrastructural megaprojects. In the light of these considerations, a second question is proposed:

Research question 2: What are the preconditions for data visualisations becoming influential in complex settings?

This second question aims to shed light on the preconditions that need to be in place to enable visualisation to shape and support organising processes in megaproject delivery. Specifically, it refers to individual, cultural, and organisational aspects – such as visual literacy and shared design conventions – that may aid or hinder the design and practice of visualisations. Building on questions 1 and 2, the third and last research question focuses more narrowly on the design of data visualisations:

Research question 3: What kind of principles guide the design and practical construction of data visualisations in megaproject management?

The question aims to unpack and theoretically develop the principles that reporting designers deploy in the constructions of visual artefacts such as dashboards, KPIs visualisations and reports. In this sense, this question focuses on the uncertain relationships between designers and users, paying attention to how designers attempt

to convey intended interactional possibilities to their products. Additionally, it aims to explore the trade-offs among aesthetic and functional ideas that guide the design of visualisations, focusing on the variety of intertwined elements that are influential in pre-forming and inducing ways of engaging and interpreting the visual artefacts in question.

1.2. Structure of the thesis

This thesis is structured as follows. This introductory chapter is followed by the literature review, theory chapter, methodology, case study, discussion, contributions, and concluding remarks. The literature review is divided into two macro-sections, the first one of which positions the concerns of this study in relation to the literature on accounting as a social, organisational and institutional practice. In so doing, this section contextualises this project within the intellectual tradition of interdisciplinary accounting. The second section of the literature review focuses on the study of the visual and is structured around the study of visuals related to accounting, an overview of experimental studies and a discussion of contributions of interdisciplinary accounting studies. The literature review shows how issues in the design and practical construction of accounting visualisations remain underexplored.

To tackle the research gaps identified in the literature review, chapter three articulates a design framework for the study of accounting visualisation. This theoretical chapter on design proposes an articulation of the notions of affordances, visual and aesthetic literacy, and visual conventions to theorise how visualisations become influential in complex settings, and the criteria that are used in their design. Chapter three concludes by positioning these design concerns with the relational ontology of sociomateriality. In chapter four, the study's methodology is discussed, explaining how the research was carried out and which choices informed the research design and case selection.

In chapter five, the empirical findings are presented through a case study that focuses on the visual practices in the Crossrail megaproject. In the discussion in chapter six, the thesis develops five interrelated design principles that advance theoretical understanding of how and thanks to which features visual artefacts support the engagement with the complexity of the megaproject. Chapter seven formalises the three key contributions of this thesis and discusses limitations, practical implications, and directions for future research.

2. LITERATURE REVIEW

2.1. Introduction and overview

The literature review shows that scholarly understanding remains underdeveloped about design criteria that make accounting data visualisations influential in supporting engagement with organisational environments defined by high degrees of uncertainty, ambiguity and dynamism. Identifying design principles that support engagement with the always unfolding complexity of such contexts poses essential theoretical and practical challenges. While studies have offered important contributions on how specific visual technologies may unfold through use in novel and transformative ways (e.g., Pollock & D’Adderio, 2012; Busco & Quattrone, 2015), much less is known about the criteria according to which designers of accounting tools practically construct purposeful visualisations (Dambrin & Robson, 2011). Theorising on the design properties of data visualisations entails a recognition that they play numerous roles beyond their alleged capacity of representing performance and notions of mediation and territorialisation (Miller & Power, 2013). Against this background, this study explores how designers of accounting data visualisations – such as project dashboards, performance reports and visualisations of KPIs – deploy specific features to pre-form interaction and manage their rhetorical relationship with users. This relationship, in which designers strive to anticipate how the user will interpret the artefact, is ambiguous and influenced by the design characteristics of artefacts and their situations of use.

To conceptualise these issues, the literature review is structured as follows. The first macro-section encompasses the following topics. Its first sub-section offers a preliminary review of the literature on accounting as a social, organisational and institutional practice to contextualise the intellectual tradition of argumentation and key reference points of study. This section draws attention to the issue of the non-essence of accounting (Miller & Napier, 1993) and makes the case of the importance of focusing on the visual as a core manifestation of the discipline. Additionally, it

critically positions the study within the body of research of the interdisciplinary tradition, tracing a brief map of its development. The second issue this review investigates is the operation of representation in accounting. The objective of the section is to show how the political nature of the discipline is not only a function of how accounting unfolds in practice but is intrinsic to its epistemological underpinnings as a practice of representation and calculation (Carruthers, 1995; Kalthoff, 2005; Espeland & Stevens, 1998). This section offers a thorough survey of the different theoretical perspectives on the issue of representation in accounting, focusing on how representations can become influential even in the absence of a referent and on how they are involved in the materialisation of ideas in visual inscriptions (Latour, 1986).

The third part of the literature review focuses on the visualisation of accounting information. This section positions the interests of this study in relation to literature concerned with visual forms *related to* accounting and those *inherent to* accounting. Research on the visual forms related to accounting (Davison, 2015) is mostly focused on the study of the layout and the pictures contained in annual reports (e.g., Preston et al., 1996; Preston & Young, 2000) and their capacity of communicating a variety of intangibles in a persuasive capacity. Contributions to this stream of studies have also highlighted the importance of visualisations in the spread of accounting technologies and the aesthetic dimension of the discipline, its figures, and figurations (see Suzuki, 2003a, b).

The review of literature of visual forms inherent to accounting discusses mainstream studies that show the impact of the visual organisation of accounting technologies empirically (e.g., Lipe & Salterio, 2000; Cardinaels, 2008). These works argue that grouping effects and visual categorisations are influential prompts for decision-making and evaluation. The concluding section discusses interdisciplinary studies that have theorised on how accounting visualisations – interpreted as ‘numerical pictures’ (Espeland & Stevens, 2008) – can function as platforms to engage with ambiguity, incompleteness and change. These contributions illustrate the transformative and

generative power of visualisations in creating markets and supporting decisions (Pollock & D’Adderio, 2012), their capacity of connecting separated fields of action (Jordan et al., 2016) as well as mediating between notions of predictability and control, and recombination and difference (Quattrone, 2015a). By highlighting some of the limitations of the existing literature, the literature review demonstrates that current research debates do not sufficiently engage with a key issue in the study of visualisations in accounting, namely the criteria according to which designers purposefully construct them. This literature review contends that more engagement is needed to address this research issue.

2.2. Accounting as a social and institutional practice

Accounting technologies and practices play a vital role in the organisation of contemporary economic and social life. Accounting is a discipline which is difficult to define in relation to its remit, impact, and margins. This is because accounting is a social science characterised by its discipline-specific theories, technologies, and eminently its profession – as well as a longstanding tradition of practice. Exploring the interconnected and often elusive effects of the discipline in its organisational and societal context has been the central concern of the interdisciplinary research approach to accounting in the last forty years. Understanding the importance of the visual medium in accounting supposes a preliminary discussion of the social and institutional roles of the discipline, to contextualise how the visual aspect of accounting technologies becomes influential.

In the late 1970s, accounting scholarship began to explore the connections between accounting technologies and practices, modes of organising and social processes that shape and are shaped by the discipline, beyond a strictly organisational focus (Hopwood, 1978). Such an approach implied a progressive detachment from economic functionalism and positivism (see Watts & Zimmerman, 1990). This encouraged the exploration of how and why “accounting has played a vital role in the development of

modern society” (Hopwood, 1976, p. 1), theorising it as a fundamental engine behind modern capitalism (Colignon & Covaleski, 1991; Bryer, 2000a, b). The interdisciplinary approach is oriented towards making accounting and its consequences visible rather than transparent (see Strathern, 2000). Early works in this tradition explored the influence of accounting in societal processes of rationalisation (Meyer, 1986), in connection with a renewed interest in institutional theory, economic sociology and the performative role of economics¹ (Carruthers & Espeland, 1991). The questions that interdisciplinary accounting scholars began to address were connected to

How had the social been intertwined with the accountings of the past and the present? What factors had been forceful mobilizers of accounting change? And what roles had accounting played in both the construction and realization of the domains of the social and the political? (Hopwood, 1985, p. 366).

Contrary to the predominant financial economics-based approach (see Watts & Zimmerman, 1990; Zimmerman, 2001), interdisciplinary scholars relied on a plethora of theoretical perspectives and methodologies borrowed from neighbouring disciplines to expand the exploration of new subject areas in connection to theoretical, political and institutional issues related to accounting (Parker & Guthrie, 2014).

Progressively, “the understanding of what counts as accounting has broadened, a greater awareness of how accounting is intertwined in the social as emerged” (Napier, 2006, p. 445). In this sense, “the accounting field can be said to encompass many of the processes and problems that deeply interest sociology scholars [...] This view places the analysis of accounting within the heartland of sociological interest” (Power, 2012, p. 294). This is particularly true about research issues in the study of

¹ A similar shift occurred in the research area of finance. Moving beyond essentialist notions of what finance is and exploring the way it works in action, scholars theorised on the performative nature of financial technologies and practices (Stark, 2009), detailing how financial models are ‘an engine and not a camera’ (MacKenzie, 2006). The focus of these studies lies mostly on the study of interaction in high-frequency trading rooms and investigates how technology is involved in constructing the ‘screen reality’ (Knorr-Cetina, 1999).

management accounting and management control, which proved to be “particularly receptive to a range of social and organizational theories” (Robson et al., 2017, p. 35). The proliferation of interdisciplinary studies contributed to reframing “accounting research using a broader, and more inclusive, albeit messier, language” (Dillard, 2008, p. 4), making the identification of the demarcation of what falls within the accounting research domain increasingly elusive. These developments, and the reason why an always increasing set of social phenomena is deemed of relevance for accounting research, is that – as Hopwood (1987, p. 207) argues – accounting has “a tendency to become what it was not” in relation to its historical development and thanks to how it has been applied to more and more domains of the administration of social life (Power, 1999; Miller et al., 2008).

In the light of these considerations, Miller & Napier (1993) contend that accounting does not have an ‘essence’ since “‘successful’ accounting methods transform the entities and practices of which they provide a calculative knowledge” (Miller & Napier, 1993, p. 632). For this reason, there is “no ‘essence’ to accounting and no invariant object to which the name ‘accounting’ can be attached” (*ivi.*, p. 631). Accordingly, accounting has also been defined in non-essentialist terms such as a ‘complex’ (Miller & Power, 2013), a ‘constellation’ (Burchell et al., 1985), an ‘ensemble’ (Miller & Napier, 1993), an ‘assemblage’ (Mennicken & Power, 2015). These definitions emphasise the ‘plasticity’ of the discipline and the fact that it can be conceived as “a form of bricolage, an activity whose tools are largely improvised and adapted to the tasks and materials at hand” (Miller, 1998, p. 619). These non-essentialist definitions emphasise how accounting can establish context-specific fields of relations between “institutions, economic and administrative processes, bodies of knowledge, systems of norms and measurement and classification techniques” (Burchell et al., 1985, p. 400).

These considerations induced an exploration of the many interrelated facets of accounting theorised as co-constitutive and co-emergent. As Hopwood (2007) argues,

these definitional complexities make claims on the nature of what accounting *is* inadequate. That is because

Accounting changes, and those changes are parts and parcel of changing social and economic relations. Accounting is a craft without an essence. [...] We need to study those changes rather than treat the present forms of accounting as immutable (Chapman et al., 2009, p. 2).

This pervasive yet elusive accounting rationality unfolds by making visible and calculable the objects at the heart of management in contextual ways. As Miller (1998) argues, what is at the boundary and the core of accounting is malleable and historically contingent. In this sense,

Accounting is most interesting at its margins. For it is at the margins that we see new calculative practices added to the repertoire of accounting. It is at the margins that accounting as a body of legitimated practices is formed and re-formed by the adding of devices and ideas of various kinds. It is at the margins that accounting intersects with, and comes into conflict with, other bodies of expertise (Miller, 1998, p. 605).

Accordingly, if accounting does not have an essence, it is also epistemologically and methodologically incomplete. In the epistemological incompleteness of the discipline resides the reason why interdisciplinary scholarship developed in constant reference to conceptual apparatuses borrowed from other research fields (Quattrone, 2000). In this sense, interdisciplinary

Accounts have often been qualified as the ‘sociology of accounting’, as the ‘politics of accounting’, as the ‘history of accounting’, or, more broadly, as ‘interdisciplinary perspectives on accounting’. [...] In these various attempts, the use of the prepositions ‘of’ and ‘on’ denotes that the theoretical development which has shed new light on accounting [...] practices happened somewhere else (Quattrone, 2015b, p. 50).

Through its hybridisation with other domains of research and expertise, accounting came to be theorised as a device for representing and acting upon entities in a transformative capacity through means of quantification and calculation. Hence, accounting “can potentially serve many interests as a tool of power, because its knowledge base has an ambiguous theoretical status” (Zambon & Zan, 2000, p. 800).

Sociologically-oriented studies unpacked how the workings of accounting can be theorised as equally administrative and political, and involved in the “calculated management of life” (Foucault, 1981, p. 140). Through its functioning as a technology for the “allocation of responsibility” (Miller & Power, 2013, p. 583), accounting provides records of actions to hold individuals to account thanks to how it enables acting on the actions of others. From this perspective, accounting is a disciplinary technology that is implicated in the orchestration of many governance programmes for intervening in economic and social life (Miller & Rose, 1993). Accounting may do so by supporting the creation of calculable economic selves that are willing to be disciplined (Hoskin & Macve, 1986) and acted upon from a distance. Accordingly, not only accounting subjectivises the actors it has forged in the light of specific prescriptions and expectations, but also it is implicated in the shaping of norms of social order (Ezzamel, 2012).

Rather than representing reality, accounting constructs various actualities by legitimating ways of thinking and being (Lehman & Tinker, 1987). Through repeated accounting practices – which in different epochs can range from mnemonic techniques and spiritual exercises (Quattrone, 2004), taxation (Lamb, 2001), online reviews (Jeacle & Carter, 2011), budgeting and planning (Oakes et al., 1998) – accounting asserts notions of social order and desirable behaviours creating a “generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, definitions” (Suchman, 1995, p. 574). Hence, the practice of accounting technologies is a crucial way through which power is woven into routinised procedures and

practices in organisations and society (see Meyer & Rowan, 1977; DiMaggio & Powell, 1983). In this sense, the discipline can be implicated in forging fields of relations that progressively become ‘taken for granted’ and create a calculative infrastructure that enables the operationalisation of neoliberal notions such as efficiency, competitiveness, and markets (Mennicken & Miller, 2012).

Hence, accounting contributes to the shaping of what is considered an appropriate organisational action, showing conformity with institutional and social norms, rules, and values. In this way “accounts are a way to display the rationality of decisions and thus enhance their legitimacy” (Carruthers & Espeland, 1991, p. 61). This legitimating function of accounting is achieved through the ways in which the discipline becomes intertwined with core values about decision-making and the very notion of ‘intelligent choice’, as the application of information to make responsible decisions. In this sense,

The gathering of information provides a ritualistic assurance that appropriate attitudes about decision-making exist. [...] Information is not simply a basis for action. It is a representation of competence and reaffirmation of social virtue (Feldman & March, 1981, p. 177).

This, in turn, shows that legitimacy is a relational construct that develops in relation to an audience, relying on sociomaterial practices and technologies of calculation (Puyou & Quattrone, 2018).

These preliminary considerations about interdisciplinary accounting research are relevant for this study for a series of interrelated reasons. If accounting does not have an essence or firmly defined boundaries, what resides at its core or periphery is always socio-historically connoted. If it is true that information visualisation is becoming increasingly influential in business and organisational practices, the visual mode might become at the heartland of accounting scholarship in the digital age (see Quattrone, 2016, 2017). This consideration is a precondition for the exploration and theorisation

of the influence of the visual format of accounting technologies in the engagement with complex settings, which is supported by the plasticity of accounting and its propensity to become theoretically and methodologically intertwined with other research disciplines. The understanding of why accounting information is visualised in specific ways and how such visualisations come to matter requires an analytical focus on the design and practice of accounting data visualisations in context.

The contributions reviewed in this section illustrate how accounting is implicated in forging social relations, the exercise of power, and in processes of legitimation of organisational and individual actions. However, these political and social aspects of the discipline are not only the outcomes of its practice and application to more and more domains of social life (Power, 1999; Miller et al., 2008), but are grounded on how accounting technologies represent organisational entities and processes. The operation of representation in accounting creates a “realm of information [*that*] is acted upon as if it was the realm of facts” (Hopwood, 1990, p. 13), which generates specific value-laden visibilities on organisational phenomena. In this sense,

The selective visibility which accounting gives to organisational actions and outcomes can play an important role in influencing what comes to be seen as problematic, possible, desirable and significant (Hopwood, 1984, p. 178).

These considerations are of importance in the exploration of the visual dimension of accounting technologies. It is now clear that the operation of accounting and its visualisation are implicated in the propagation of norms of order and desirable behaviour. Hence, they cannot be regarded as neutral. In the light on these considerations on the political nature of the discipline, the next section problematizes the operation of representation in accounting. In so doing, it makes a case for focusing on the visual aspects of the discipline as a fundamental factor that influences how and why accounting technologies come to matter.

2.3. The operation of representation in accounting

In that Empire, the Art of Cartography attained such Perfection that the map of a single Province occupied the entirety of a City, and the map of the Empire, the entirety of a Province. In time, those Unconscionable Maps no longer satisfied, and the Cartographers Guilds struck a Map of the Empire whose size was that of the Empire, and which coincided point for point with it. The following Generations, who were not so fond of the Study of Cartography as their Forebears had been, saw that that vast map was Useless, and not without some Pitilessness was it, that they delivered it up to the Inclemencies of Sun and Winters. In the Deserts of the West, still today, there are Tattered Ruins of that Map, inhabited by Animals and Beggars; in all the Land there is no other Relic of the Disciplines of Geography.

Purportedly from Suárez Miranda, *Travels of Prudent Men*, Book Four, Ch. XLV, Lérída, 1658.

Borges (1998, p. 160), *On Exactitude in Science*

Miller & Power (2013, p. 563) argue that accounting is possibly “the most powerful system of representation of social and economic life that exists today”. Representation is a central issue in accounting theory, and this section focuses on epistemological considerations concerning the status of accounting representations. The inquiry into the meaning of representation, its workings, and the conditions of its possibility emerged as a response to the positivist epistemology of mainstream accounting research. Positivist approaches assume that “like journalists, accountants should report the news, not make it” (Solomons, 1991, p. 187). That position is grounded on a separation of facts from values (Friedman, 1953), which is understood as the precondition for objective notions of correspondence and ‘true and fair’ accounting representation. The critical exploration of these concerns, which dates to the beginning of interdisciplinary accounting research, shows how the non-neutral and political nature of the discipline is not only a function of how accounting unfolds in practice, but is *intrinsic* to its epistemological underpinnings as practice of representation and calculation (Hines, 1988; Morgan, 1988). In this sense, the interdisciplinary tradition explored issues of representation of accounting information, stressing how “the map is not the territory [...] and the word is not the thing” (Korzybski, 1995, p. 58).

The aura of objectivity and neutrality that pervades quantitative measures can be interpreted as a by-product of the power of numbers. As Espeland & Stevens (2008, p. 417) argue:

The authority of numbers may be vested in (1) our sense of their accuracy or validity as representations of some part of the world [...] (2) in their usefulness in solving problems [...] (3) in how they accumulate and link users who have investments in the numbers [...] or (4) in their long and evolving association with rationality and objectivity.

The reasons that Espeland & Stevens (2008) identify as laying behind the authority of numbers are directly connected to the notion of representation and their alleged representational power. Though their quantitative appeal, technologies of calculation tend to be given authority even in the absence of a defence of their validity because “a decision made by numbers has the appearance of being fair and impersonal. [...] Quantification is a way of making decisions without seeming to decide” (Porter, 1995, p. 8). In this sense, accounting representations and classifications are political statements characterised by a silent epistemology:

It is this unawareness of the power of representations and the perspective that they inevitably take that makes the [...] users believe that these numbers are facts, incontestable values where the correctness of the calculation implies its justness, making people forget that facts are always made (Quattrone, 2015b, p. 53).

Accounting figures offer a means through which it is possible to represent the workings and processes of an organisation, in a way that is inherently simplified in nature and allows to bring the outside in. In this sense,

What is accounted for can shape organizational participants' views of what is important, with the categories of dominant economic discourse and organizational functioning that are implicit within the accounting framework, helping to create a particular conception of organizational reality (Burchell et al., 1980, p. 5).

This conception of organisational reality is partly grounded in the representational status attributed to accounting. If accounting cannot represent reality 'as is', as a full picture, then the alleged objectivity of its figures "is always as much a part of the observer as of the object observed, and [...] accounting systems do more than just monitor or mirror reality; they also shape reality" (Morgan, 1988, p. 482). Accounting scholars that adopt this line of enquiry are concerned with how "accounting truths [...] are made, not found" (Macintosh, 2009, p. 209) and explore these issues by highlighting the perspectivism of knowledge and representation. Even if there may be a world independent of language and representation, this world can only be known through such a language, which is to be understood as a social and always negotiated accomplishment that can offer only value-laden 're-presentations'. In the light of these considerations regarding the idea of accounting as a non-neutral interpretive frame (Carruthers & Espeland, 1991), or even 'interpretative art' (Morgan, 1988), accounting scholars explored the issue of representation employing a plethora of theoretical perspectives.

Carruthers (1995, p. 313) discusses the roles of accounting representations "as one of a larger set of features that can legitimize organizations through the construction of an appearance of rationality and efficiency". Carruthers employs the development of Wittgenstein's philosophy as a metaphor for describing how the issue of representation has been tackled in interdisciplinary accounting². Following Wittgenstein's

² Carruthers (1995) contends that the mainstream picture of accounts postulates the capacity of numbers to represent organisational phenomena in an analytical manner, through figures that are representative of the state of the world. This working is comparable to Wittgenstein's (1922) theory of picture representation, which is grounded on the belief that a proposition is a linguistic sign which exhibits a state of affairs thanks to the denotation of its constituents (biunique correspondence between constituents and objects) and to its logic structure (how the constituents are correlated). Elements of the proposition are believed to correspond to elements of reality directly: Names stand for objects and relations among signs stand for relations among objects.

Philosophical Investigations (1958), Carruthers argues for a shift from the aspirational goal of picture representation to the importance of emphasising its pragmatic elements. In this sense,

Attention should be shifted from the ‘syntax’ and ‘semantics’ of accounting and focused on its ‘pragmatics’. Accounting has a more fundamental role than the accounting as mirror version suggests [...]. Furthermore, Wittgenstein’s concept of ‘language games’ leads directly to the question of audience [...]. Who finds the game compelling? It is likely that accounting principles are not necessarily generally accepted, and that one must construct a more nuanced picture of the audience(s) for accounts. Determining who can participate in accounting language games involves a consideration of professional jurisdictions (Carruthers, 1995, p. 321).

This move from the ideal of *picture representation* to socially negotiated ideas of *language game* and *family resemblance* (Wittgenstein, 1958) has been influential in accounting. Mouritsen (2010, p. 228) discusses the importance of studying how “accounting numbers are constituted through language games which make the operation of representation one where language mediates the 'real', and there is a possibility to express the world in certain ways”. Employing a similar strategy but drawing from the philosophical work of Quine, Tinker (1991) theorises on the arbitrariness of signification of accounting as symbolic form, focusing on the implications of such arbitrariness for validity claims. He shows how the accounting ‘language’ and ‘reality’ cannot be conceived of as independent from each other and, for this reason, one (reality) cannot serve as the stable epistemic referent of the other (language game). Similarly, Quattrone (2000) proposes a framework for trans-disciplinary accounting research that shows how the consistency of any system of meaning implies a reference to a broader system of knowledge, and the acknowledgement of such relativism is a methodological necessity to avoid ontological gerrymandering (see Woolgar & Pawluch, 1985; Arrington & Schweicker, 1992).

The issue of the nature of accounting representation has also been approached relying on hermeneutics. Building on the notion of language game, and drawing from the works of Gadamer and Rorty (1992), Boland (1979, 1989, 1993) speaks of a ‘hermeneutical turn’ in accounting pointing to the defining feature of this approach as based on

An acceptance and appreciation of ordinary language with all its attendant ambiguity as the only basis we have for all we can know [*and a*] realization of our own deep, personal involvement in interpreting our inherently symbolic and multi-vocal everyday language in constructing all we know (Boland, 1989, p. 216).

Consistently with his philosophical premises, Boland (1979, 1989, 1993) advocates for a rejection of the subjective-objective dichotomy in the study of representations and refuses the analytical distinction between accounting expression and organisational reality. Similar conclusions – which can be conceptually comprised in Gadamer’s claim that understanding implies always understanding *differently* – have also been achieved by scholars who rely on different theoretical lenses. Contributing to the idea of representation as inaccurate negotiated controversy Robson (1999), drawing from FASB’s conceptual framework, illustrates how representation can be a dominant social and institutional force even in the absence of the notion of a referent. He stresses the centrality of an often-overlooked aspect of the problem, namely that “there is no representation that is independent of the apparatus of representation” (Robson, 1999, p. 621).

Bloomfield & Vurdubakis (1997) discuss how information systems can be understood as ‘practices of worldmaking’ (Goodman, 1978) that create ‘visibilities’ and give ‘presence’ to a set of technically constructed facts that define possibilities for interactions among organisational participants. They are hence involved in the process of enframing (Ciborra & Hanseth, 1998). Enframing is a social performance that is both resource and effect of visual and technical practices through which subject and

object of action, context and content are constituted. In this sense, information systems shape

Organizational activities, events and objects are therefore (re)defined in terms of the demands and principles of the system, and their worldly referents have to be (albeit temporarily) reconciled with them. The construction of a rational order is thus dependent on members' willingness to (re)cognize and (re)create their world and their work in terms of such constructs (Bloomfield & Vurdubakis, 1997, p. 664).

Lorino et al. (2017, p. 2) explore the relationship between accounting representations as “generic meaning frames” and the way these numbers are engaged in “malleable local framing and (re)framing processes” to understand organisational change. From their perspective, the possibility for re-framing resides in the dual nature of accounting representations, which are both contextually-situated and generically-modelled.

The theorisation of the operation of accounting representation in connection with its social context occurred through a rich tradition of accounting studies that draw from Actor-Network Theory (ANT) (see Latour, 2005). The ANT perspective, which aims to overcome the divide between ‘social’ as opposed ‘non-social’ actors, shows how agency can be applied to ‘non-human’ actants thanks to their capacity of leaving visible traces in the construction of networks of associations. This approach focuses on how centres of calculation, namely sites in which knowledge production builds upon the gathering of resources through circulatory movements to other places (e.g., the State), act and exert control from a distance. The study of action at a distance is linked to representation, as “problems of correspondence between representations and their referents do not arise [...] if one is located in the context one wishes to act upon” (Robson, 1992, p. 691). In this sense,

If knowledge is oriented towards acting upon a remote setting, then it is produced and sustained not by ‘true’ correspondence but by its power in

securing long-distance control, through the provision and maintenance of networks for the gathering, transmission and assimilation of inscriptions. Inscriptions translate the elements of the context. [...] The more remote [...] the actor is from the setting he or she wishes to act upon, the more translations or forms of the setting ('information') need to be mobilised in order to overcome the problem of distance (Robson, 1992, p. 691).

The notion of inscription as something that “refers to all the types of transformations through which an entity becomes materialised into a sign, an archive, a document, a piece of paper, a trace” (Latour, 1999a, p. 306) and the idea of accounting as inscription device that can translate entities in accounting measures and visualisations that can be made actionable is of particular importance³. From this perspective, inscriptions are signs that refer to an entity without being able to represent it fully⁴ (Latour, 1986) and have therefore the status of incomplete representations.

According to Latour (1986), the properties of inscriptions are grounded on the fact that they are *mobile*, as they can move from context to context, while being *immutable*, in

³ However, in the study of translation processes in the design of purposeful artefacts, it is worth keeping in mind the importance of their material aspects. That is because, as Pentland & Feldman (2008, p. 243) pointedly remark: “A personal computer can be translated as a plant stand [...] [*but*] no amount of translation will turn a toaster into a mobile phone”.

⁴ A fundamental aspect in the production of accounting inscriptions is the process of commensuration, namely the transformation of qualities into quantities (Robson, 1991; Espeland & Stevens, 1998). Accounting supposes the reduction of entities into a common metric. Hence, the content of quantitative statements is an assertion about a concept rather than an object. Since “quantities express an identity between the concept counted and the number (of instances)” (Robson, 1992, p. 688), it is not possible to establish a clear-cut distinction among qualities and numbers, as the latter are qualities in identity with themselves. Commensuration, in order to occur, has to render invisible and irrelevant features of the qualitative domain, as commensuration “denies the possibility of intrinsic value, pricelessness, or any absolute category of value” (Espeland & Stevens, 1998, p. 324). This is apparent, for instance, in the case of university rankings which are involved in processes of distortion and magnification insignificant differences among the entities they are expected to represent (Espeland & Sauder, 2007). Similarly, initiatives such as worldwide census activities (Kostelnick, 2004; Barton & Barton, 1993) and formal accounting procedures (Meyer, 1986) are clear examples of how measuring, reporting, ranking, and visualising processes are involved in the making and remaking phenomena and relations they ostensibly represent (Pollock & D’Adderio, 2012; Pollock et al., 2018). These considerations are indicative of how the idea of representation is merely inspirational: “Although clearly accounting is employed with some intention of representation, at best this representation is always partial in that representation is always produced in the absence of its referent. Accounting techniques depend upon procedures of measurement, classification and recording that can be applied to a domain of activities. [...] Events that are not easily rendered into financial quantities tend to be overlooked, or bracketed as ‘qualitative’ issues” (Robson, 1991, p. 551).

the sense that they persist in their form. Through the processes of translation and reification, they are made *flat*, in a way that makes easy to handle them, and their *scale* can be altered without affecting their internal proportions. Because of these properties, they can be *reproduced* for diffusion and mobilisation purposes, and they can be combined and *recombined* to create new connections. This recombination affords the *superimposition* of different inscriptions that can give visibility to new relationships (e.g., overlapping different curves in a graph). Similarly, inscriptions can be made *integral to written text* and, thanks to their (often) two-dimensional nature can be merged with *geometry* and proportion to visualise anything in the form of graphics, numbers, and tables. These properties are the reason why inscription devices are central to the study of accounting

By means of inscription, reality is made stable, mobile, comparable, combinable. It is rendered in a form in which it can be debated and diagnosed. Information in this sense [...] is itself a way of acting upon the real, a way of devising techniques for inscribing it in such a way as to make the domain in question susceptible to evaluation, calculation and intervention (Rose & Miller, 1992, p. 185).

However, it is important not to reify the operation of inscription devices. Inscriptions should not be understood as finite and isolated objects or, to use Latour's (2005) lexicon, as 'matters of fact'. They are instead 'matters of concern', namely the always unfolding results of networks of humans and non-humans that 'negotiate' over controversies. Such gatherings are interfaces involved in "making facts more visible, more risky, more costly, more debatable, more interesting and more publicly relevant" (Latour, 2005, p. 115).

The ways in which this contested dimension comes to life is connected to the only feature that unifies Latour's (1986) discussion of the properties of inscriptions: Being visual. Focusing on this aspect of accounting information, beyond their alleged representational capacity and inspirational goal of correspondence and accuracy

(Mouritsen & Kreiner, 2016), and paying attention to its design properties has certain advantages over its analysis as language game:

It is not wrong to claim that there are language games; but it is slightly different to saying that there is a visualisation because the latter does not disappear when the word has been spoken. The visualisation is durable so that it can be transported over time and space and be recalled. The word is not lost in language. The visualisation keeps words in place and can only be transformed by intervention. Language games are social; but visualisations are even more social because they require explicit contradiction in order to be re-made. It requires intervention (Mouritsen, 2010, p. 231).

The theoretical point made by Mouritsen (2010) is of foremost importance for this study. The focus on its material manifestation enables a precise investigation of how accounting is made possible through investment in visual forms that are situated in organisational practices (Knorr-Cetina & Bruegger, 2002). An investment in visual forms can alter entities, events, and processes into forms that are accepted in a setting and can circulate and gain conventional currency in specific circumstances (Thévenot, 1984). The materiality and ‘stability’ of visualisations allows focusing on how such artefacts draw things together that cannot be naturally perceived. In this sense, visualisations represent the materialisation of ideas (Czarniawska-Joerges & Joerges, 1995) that can generate other ideas that in turn may materialise themselves.

The concerns raised by these studies about representation in accounting are of importance for the study of the design of data visualisations. Not only they draw attention to the incomplete and arbitrary nature of accounting representations, but they also highlight that such representations can be powerful even in the absence of referents that can be directly signified. The idea of accounting as a language game bound by (mostly) implicit sets of rules emphasises the relevance of the performative aspects of accounting technologies. Additionally, as it appears from the contributions of studies that rely on ANT, the visual properties of inscriptions are privileged sites to explore how social relations and ideas are materialised into artefacts that require

intervention to be altered. Capturing this process has been a central concern of scholars that explored the visual manifestations of accounting technologies, which are reviewed in the following section.

2.4. Visualising accounting

We are living the sociological experience of a society more and more pervaded by images, visualisations, graphs, charts and matrixes. Eminent sociologists and philosophers contend that ours is an increasingly visual society and visual forms are progressively more widespread and influential in the age of mechanical – as well as digital – reproduction (see Debord, 1970; Benjamin, 2008; Bauman, 2000). As Drucker (2011, p. 2) argues, “the history of knowledge is the history of forms of expression of knowledge, and those forms change”. Accordingly, accounting research has reflected the trend of an increasing interest on the visual medium in the study of its technologies and their technical, social, and economic consequences. The field of the study of the visual in accounting, which blossomed in the last twenty years, configured itself as a highly interdisciplinary area of research that relies on a variety of approaches and theoretical perspectives which include art theory (Armstrong & Tomes, 1996), visual semiotics (Davison, 2007), visual rhetoric (Quattrone, 2017), visual sociology and Actor-Network theory (Justesen & Mourtisen, 2009), impression management (Neu et al., 1998), and visual psychology (Beattie & Jones, 1992) to mention just some of the most popular streams. Rhetorically mimicking Rorty’s (1992) idea of the ‘linguistic turn’, interdisciplinary scholars in accounting often refer to a ‘visual turn’ (Davison, 2011, 2015) to contextualise the increasing interest on visual forms as expressive, persuasive, and performative media.

Visual forms are of foremost importance to accounting. Since its genesis, the very construction of an account is an activity with eminently visual components (Ezzamel, 2009), which supposes the mastery of conventional, rhetorical and graphical codes. Additionally, the way in which accounting information is visualised is not neutral both

in the sense that it conveys specific and value-laden visibilities (Hopwood, 1996) and in the sense that the visual configuration of accounting technologies plays an agentic role in decision-making (Cardinaels, 2008), interpretation and interaction (Quattrone, 2017). Technological advancements in digitalisation, and more recent phenomena such as big data analytics tools, are making the amounts of information on which to base managerial decisions always more significant. Given the capacity of visualisations of condensing and making information meaningful by enabling the perception of trends, visual forms are now omnipresent in the business world (Morrison & Wensley, 1991). In the light of these social and technological conditions, and the incumbent need of identifying criteria for filtering and simplifying information (Pollock & Campagnolo, 2015) to make it actionable, more attention is to be put on the “*form*, as well as content and context” (Gallhofer & Haslam, 1991, p. 40, emphasis added) in the study of accounting.

This study makes a case for a design approach – namely an approach based at the same time on design theory as well and on an analysis of the design features of visual artefacts – to the study of accounting visualisations. In so doing, this section surveys the relevant literature in visual research in accounting. For analytical convenience, this section divides the literature into two broad categories, namely that which studies the narrative and discursive aspects of visualisations related to accounting (e.g., pictures in annual reports), and that which focuses on how accounting and performance management visualisations (e.g., dashboards) enable to act on complex settings.

2.4.1. Visual forms related to accounting: The persuasive and discursive aspects of accounting visualisations

As Tversky & Kahneman (1986) have demonstrated, visualisations can engender thought patterns and may have important framing effects. The ‘framing effect’ is a cognitive bias whereby people faced with a decision scenario react differently depending on how information is presented. Additionally, as Tversky (1974) has

shown, individuals presented with visual and linguistic material to analyse devote approximately twice the time to examining the visual, and visual material is particularly influential in cognitive memory (Anderson, 1980). Similarly, Townsend & Shu (2010) show that factors such as aesthetics, visual design and quantity of pictures and colours influence behaviour involving the valuation of hypothetical investment decisions for companies where design has no inherent value. These experimental contributions highlight the importance of visual forms in influencing decision-making and evaluation.

In the interdisciplinary tradition, the roles of visual material in accounting have been explored relying on a variety of methodologies and approaches. This strand of research “has pushed the interdisciplinary boundaries to become theoretically rich, eclectic and inventive” (Davison, 2015, p. 125). Such eclecticism is reflected in studies that explored the narrative and discursive aspects of the discipline, namely the “visual forms *related to* accounting” (Davison 2015, p. 123, emphasis added). As the qualifying function of the term ‘related to’ implies, these studies focus mostly on factors that are not inherent to accounting technologies but are nonetheless influential in communicating a variety of intangibles in a persuasive – or even manipulative – capacity. A common theme “running through most discussions on the visual in annual reports is the attempt by the firm to convince an audience about the firm’s capabilities and futures” (Justesen & Mouritsen 2009, p. 973). Visualisations are influential in this process, and that is why “annual reports have become imbued with visual images that frame, and frequently eclipse, the accounting statements” (Davison, 2014, p. 20). These studies compellingly show how

The visual mode of social reality construction – in particular through the manifest content of visual artifacts – implies greater facticity, eliminating predication and logical conjunction, disguising itself as information rather than argument, and as an accurate map of the world rather than a construction of reality, thus enhancing its coerciveness (even though such coerciveness is never made explicit) (Meyer et al., 2013, p. 491).

Beattie & Jones (1992) discuss the use and abuse of graphs in annual reports. They identify in the issues of selectivity and the non-compliance with the principles of graph construction central causes of visual distortion of financial information. They also show that companies with 'good' performance tend to rely more heavily on graphs and visual distortions generally portray performance more favourably. In a later study, Beattie & Jones (2002) experimentally link measurement distortion with users' perception of financial performance. They show that distortions of more than ten per cent are to be regarded as manipulative and they unsurprisingly find that users with little financial literacy are more at risk of being deceived by graphical misrepresentations. However, the studies by Beattie & Jones (1992, 2002) are based on the representational assumption that is possible to draw a line a priori between what is persuasive and what is not. In this sense, they do not recognise that "every chart is a manipulation" (Berinato, 2016, p. 151) and provide limited insights on how such graphics may influence users beyond their alleged representational value.

In a survey of the evolution of annual reports from the 1960s to the 1980s, Lee (1994, p. 215) shows that reports shifted from "predominantly accounting communications of corporate financial performance to stylised non-accounting projections of corporate identity in a consumer-oriented world". Preston et al. (1996) shed light on the representational, ideological, and constitutive roles of images included in annual reports in the 1980s and 1990s. They stress the significance of images as ways through which corporations present themselves to different audiences and illustrate how these pictures are opportunities to theorise on the involvement of the visual in the creation of different 'ways of seeing' organisational realities. Relying on Neo-Marxist and postmodernist theories, Preston et al. (1996) propose four ways of interpreting visual material: As reflection of a basic reality, as a way of masking and altering a basic reality, as a way of masking the absence of such a reality, and as a way of constituting rather than representing reality. The same issue has been later tackled by Preston & Young (2000), who contend that pictures in annual reports are involved in the construction of the idea of the 'global corporation'. In this sense, pictures in annual

reports are persuasive devices to convince the audience that the images are both the representation of the corporations themselves as well as the globalised society.

Following a similar line of enquiry, Graves et al. (1996) link the increasingly visual nature of U.S. annual reports with the ‘television epistemology’ that emerged from the 1960s onwards. Such an epistemology, they claim, assumes that for any discourse to be valid it has to be compatible with a television format, which is expected to be glamorous, colourful, and entertaining. They contend that the increasingly pleasing design format is a powerful device that supports the truth claims of the reports. Similarly, Davison (2010) analyses visual portraits of the business élite and the way they encode intellectual, symbolic, and social intangibles through their dissemination in annual reports. Davison (2011) studies the covers of Ernst & Young’s annual reports employing a framework based on Barthes and illuminates the metatextual nature of accounting communication showing how visuals are used to communicate

Antithetical messages regarding accountancy, which is portrayed as simultaneously an art and a science, creative and measured, dynamic yet reliable, spontaneous while constrained, alert to surprise and opportunity as well as being grounded in well-worn professional care and routine (Davison, 2011, p. 276).

What this stream of studies shows is that visualisations, in the form of photographs and pictures in annual reports, may work as persuasive devices that are influential in impression management and that manipulate the perceptions of specific audiences. However, their objects of inquiry are not accounting technologies. That is because the images these studies investigate are visual accessories that do not have an inherent connection with the accounting numbers themselves or how they visually and materially are orchestrated. Additionally, the rhetorical analysis conducted is often occurring at the formal level, without reference to the practice or interpretation of annual reports. In this sense, while the mobilisation of postmodernist and neo-Marxist

theories provides intriguing insights into the power of pictures, the power of the above is assessed without reference to their practice, thereby remaining speculative.

A different research stream, which is not concerned with the cosmetic aspects of visualisation, has theorised aesthetic concerns as crucial aspects that are inherent to accounting as a visual technique. Cooper et al. (1994) contend that there is an intrinsic aestheticism in the roots of accounting and this can be seen in the very ideals of ‘balanced’ accounts and statements (see Cooper et al., 2017). Thompson (1991) argues that models based on verbal language and its linear assumptions not be appropriate to appreciate the rhetorical and visual nature of accounting from Pacioli’s early double-entry bookkeeping onwards. He also calls for research on the role of notions of symmetry, balance, and proportions in the study of accounting. In a later study, Thompson (1998) emphasises how it is through forms of visualisations (e.g., tables, charts, and diagrams) that knowledge of the firm and the economy are constructed. He calls for a reflection on the following challenging questions, which remain largely unaddressed:

Why have we become accustomed to the ‘taken-for-grantedness’ of such techniques of visualization? What is their historical specificity and what are the conditions of existence of such a taken-for-grantedness? A very striking feature of textbooks in the social sciences [...] is how it is those dealing with economics and accounting above all else that make the maximum use of charts, diagrams, figures, symbols and tables in representing the object of their analyses and in exploring their respective analytical procedures. But this was not always so. In addition, just as there are many techniques of visualization, so there are many ‘interpretations’ of the significance and outcome of the analysis embodied within those visual representations. The ‘truth’ of the state of the economy or the firm is thus a contested one, contested via the manner in which their analytical visualization is conducted (Thompson, 1998, p. 286).

Thompson (1998) investigates how visualisations become ‘analytically operative’ by shifting the focus from their representational aspects to their constitutive and interventionary aspects. In so doing, he calls for research on how intelligibility,

knowledge and understanding are *effects* of the engagement with various forms of visualisations instead of their preconditions.

Suzuki (2003a) further contributes to this research agenda discussing the epistemological underpinnings of the national accounts during their construction in the 1940s. Suzuki (2003b), drawing from examples of the earliest *Tableau Economique*, explores the interplay between accounting and macroeconomics, drawing attention to how financial accounting has been consequential for the spread of economic ideas. Such spread, Suzuki (2003b) argues, did not occur thanks to the representational capacity of afforded by the discipline, but because of how different the visual forms of accounting, in connection to its language and techniques of calculation, gave life to a self-perpetuating apparatus. The construction of the ‘economic society’ by accounting figures and visualisations relied on rhetorical claims about accounting’s ability to measure phenomena objectively:

The use of numbers in macroeconomics may have its root, at least in part, in the aesthetics of formal presentation, which is in accordance with the traditional epistemic values. In other words, numbers in economics may have been used not for a logical-epistemological reason, but for a rhetorical-epistemological reason (Suzuki, 2003b, p. 73).

For similar reasons, Puyou & Quattrone (2018) stress that accounting ‘numbers’ should always be understood as *figures*, namely as material artefacts having an intrinsic aesthetic code based on ideas of balance, proportion and symmetry: “They are figures with a material and aesthetic dimension to them, not mere numbers resulting from immaterial formulae and calculations” (Puyou & Quattrone, 2018, p. 10). The visual articulation of both forms *related to* accounting and *inherent to* accounting had major historical significance in the spread and institutionalisation of the discipline and are powerful rhetorical tools that are influential in the discipline and beyond. These contributions show that “non-design is not an option, because design is already embedded in management’s ‘logic of visualization’” (Hoskin, 2004, p. 146).

Building on these insights, the next section discusses studies that explore how visualisations support engagement with complex organisational contexts.

2.4.2. Accounting visualisations as platforms to engage with ambiguity, incompleteness and change

A different research stream in interdisciplinary accounting investigates the roles and constitutive power of visualisations in supporting engagement with incompleteness, ambiguity, and the dynamism of complex organisational settings as well as creating new visibilities on organisational phenomena (e.g., Qu & Cooper, 2011; Pollock & D'Adderio, 2012; Busco & Quattrone, 2015; Jordan et al., 2016). This stream of studies focuses on the visual format of accounting technologies themselves (e.g., the visual and design configuration of a Balanced Scorecard or a two-by-two matrix), generally employing a micro-level perspective. Building on this second stream of literature, the focus of this section lies on how visual design characteristics of accounting technologies can unfold in use, and on their potential emergent properties. In this sense, the studies discussed in this section relate more closely to visualisations used for management accounting purposes rather than for external disclosure of financial information, and the emphasis lies on how they support decision-making and performance evaluation in diverse organisational contexts. This section is divided into two subsections, the first of which reviews contributions from mainstream and experimental accounting whereas the latter discusses interdisciplinary research contributions.

2.4.2.1. Contributions from mainstream and experimental accounting research

The investigation of the influence of the visual configuration of accounting information on decision-making has been an object of enquiry in the mainstream accounting tradition. Cardinaels (2008) emphasises the importance of the visual presentation format of accounting information (i.e., graphs versus data tables) and

suggests that is paramount for firms to tailor presentation formats to the level of accounting knowledge of specific user groups. Investigating experimentally the profit impact of different ways of visualising cost reports, Cardinaels (2008) shows that managers with lower level cost accounting skills tend to be better supported in their decisions by graphs, while users with a higher level of accounting knowledge tend to perform better relying on tabular formats. This finding is significant because it highlights that while it is undeniable that “the power of a graph is its ability to enable one to take in the quantitative information, organize it, and see patterns and structure not readily revealed by other means of studying the data” (Cleveland & McGill, 1984, p. 535), ‘user friendly’ data visualisations may undermine the ability of experienced decision-makers in forming their own mental picture of cost performance. Similarly, while one could argue that graphical excellence is something that “gives to the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space” (Tufte, 1983, p. 160), it may also create noise and not be fit for purpose for many decision-makers. Experimental research has also shown that in the evaluation of three types of reports for forecasting purposes (i.e., only numerical, only graphical, and combining numeric and graphical data), graphical formats can marginally improve the accuracy of forecast judgments compared to the alternatives (Desanctis & Jarvenpaa, 1989).

Lipe & Salterio (2000) investigate the human information processing demands of the balanced scorecard (BSC) and show that decision heuristics are affected by the design of the tool, which affects performance judgements determined by the inclusion of diverse measures. They contend that it is paramount to pay attention to the design of the tool as unique measures in a BSC may systematically be underweighted in performance evaluation. Paying attention to this issue, they argue, is fundamental if the BSC has to achieve the purpose according to which Kaplan & Norton (1996a, b) conceived of it:

Since financial measures are often common across business units, the unique nonfinancial measures may receive less attention. Underweighting

nonfinancial and leading measures undermines the goal of the BSC, which was expressly designed to incorporate such measures in managerial thought and decision-making (Lipe & Salterio, 2000, p. 294).

In a later study, Lipe & Salterio (2002) further explored the judgmental effects of the BSC's design paying attention to how people engage with the high number of subcategories included in each of its four dimensions. They find that

When multiple measures within a BSC category show consistent performance (e.g. above-target), managers' evaluation judgments are reliably different from evaluations made using these same measures without the BSC format. These judgment differences disappear when the measures indicating strong performance are distributed throughout the four BSC categories instead of being found in a single BSC category (Lipe & Salterio, 2002, p. 531).

Cardinaels & van Veen-Dirks (2010) expand the findings of Lipe & Salterio (2002) showing experimentally that specific changes in the visualisation of information in a BSC (e.g., the addition of performance markers) can help to increase the weight evaluators assign to non-financial indicators. They also point out that when performance differences are located in one of the non-financial categories, visualisations do not seem to have tangible effects. These findings are significant not only because they corroborate the importance of the visual organisation of accounting technologies, but also because they show that grouping effects and visual categorisations of indicators are influential prompts for decision-making, evaluation and the exercise of judgement.

2.4.2.2. Contributions from interdisciplinary accounting studies

This stream of study encompasses a series of works that have explored how different forms of visualisations unfold in practice, theorising on the novel and potentially unexpected associations and domains of action they may generate through their

practice. From this perspective, visualisations of accounting information can be regarded as ‘numerical pictures’:

Call them pictures with numbers, or numerical pictures: the point is that many of our most consequential representations of the world are made quantitatively. Those who produce and consume such pictures for a living want them to be *not only errorless but also compelling, elegant, and even beautiful*. It is more than a matter of esoteric connoisseurship. The appearance of numerical pictures matters greatly to the gatekeepers who determine their publication in books and scholarly journals, and to the policymakers [*and managers*] who make consequential decisions on the basis of the information contained within them (Espeland & Stevens, 2008, p. 422, emphasis added).

The visual dimension of such ‘numerical pictures’ is integral to the study of accounting as a situated calculative technology (Miller & Napier, 1993). As discussed previously, given the abstractness of its categories accounting can be said to count the invisible (Meyer, 1986), and therefore cannot provide ‘true and fair’ representations that afford correspondence with external realities. Since accounting is a non-representational practice (Tinker, 1991), its visualisation is an intrinsically transformative process. A process occurs through a transformation of the invisible into the visible, transmuting absence into presence (Miller & O’Leary, 2007). The visualisation of accounting information is, therefore, a process through which “a visibility [*becomes*] reality” (Hopwood, 1987, p. 225). Accordingly, visualisations – such as two-by-two diagrams (Pollock & D’Adderio, 2012), risk matrices (Jordan et al., 2016), logical frameworks (Martinez & Cooper, 2017), and dashboards (Quattrone, 2017) – are powerful because they can prompt constitutive processes that go beyond representation, such as territorialisation and mediation, working as engines and rhetorical machines that stimulate reflection and innovation (Revellino & Mouritsen, 2015; Busco & Quattrone, 2018b).

As Espeland & Stevens (2008, p. 425) argue, “numerical pictures are not clear glass windows. They color and refract what comes through” their design features and visual

characteristics. Such refraction is mediated by how visualisations can become involved in epistemic practices that embody and routinise norms of scepticism and certainty about the world (Kalthoff 2005; Knorr-Cetina 1999). Quattrone (2009) explores what enabled the emergence of accounting as a performable technique that spread across economies and societies. He does so by studying the interrelationships between accounting as a method for the organisation and classification of thinking and knowledge, its ‘orthopraxis’ nature, its dependence on images and visualisations, and the sociomaterial artefacts through which accounting technologies are materialised. Through reflexive engagement with its visual-material instantiations, the accounting method of classification and organisation of knowledge can lead to a practice that can balance between notions of predictability and control, and recombination and difference (see Boland, 1979; Hedberg & Jönsson, 1978). For Quattrone (2009, p. 109), the power of visuals resides in the attitudes they sustain rather than in their content. Visualisations can “contain very little”, nonetheless they “effectively communicate and engage the user in a performative exercise” (*Ibid.*). Similarly, Quattrone (2015a), theorising the procedural and non-substantive logic of accounting, shows how the visual-rhetorical accounting representations of the Jesuit Order were not aimed at providing objectivity, rather they acted as incomplete ways to classify, order, and invent arguments about organisational and intellectual matters. From this perspective, “the visual organization of accounting produces order, allows for immediate recognition, and engages users in repeated accounting performances” (Jordan et al., 2016, p. 4).

Jordan et al. (2016) show that one of the fundamental reasons behind the popularity risk matrices is their capacity of appealing to different audiences and establishing links between diverse organisational contexts. Their spread is interpreted as due to their interdiscursive appeal rather than to their functional purposes or representational accuracy – in this sense, the *relationality* enabled by such matrices may often be more influential than their *referentiality* (see Kornberger et al., 2017). Following a comparable line of inquiry, Themsén & Skærbæk (2018) explore the visual power of risk management technologies in the management of a megaproject. They show how

visual inscriptions are constitutive in establishing the boundaries of the types of uncertainties that are categorised as risks. Specifically, they look at how inscription devices are implicated in a distortion of performance that leads to repeated reframing efforts in “a continuous process of search for perfection” (Busco & Quattrone, 2018a, p. 16).

Interdisciplinary studies on the visual properties of the Balanced Scorecard that rely on the ANT notion of inscriptions have provided valuable contributions to the study of the visual in accounting. For instance, Cooper et al. (2017) contend that one of the fundamental reasons that supported to the popularisation of the BSC was its visual power and the capacity it has of “facilitating framing by rendering interactions visible, imposing order, and limiting externalities” (Cooper et al., 2017, p. 1012). This, in turn, is connected to the effectiveness of visualisations in persuading and winning over people with sceptical views and gain their support (Kaplan & Norton, 2004). In this sense, by making information visible in front of other people’s eyes, compelling images can muster “the largest number of well aligned and faithful allies” (Latour, 1986, p. 4). Similarly, Qu & Cooper (2011) investigate how consultants populate the BSC with information. They discuss how visualisations are “persuasive in communicating information [*and*] solidify ambiguous concepts into concrete forms” (Qu & Cooper, 2011, p. 358). With their focus on how the design of inscriptions can mediate conceptual ambiguity, they emphasise the potential of artefacts that include interpretative flexibility in their design: “Interpretative flexibility allows different groups to conceive their own version of a technique to make it useful in their particular circumstances” (*ivi.*, p. 347). Along with a similar line of enquiry, Busco & Quattrone (2015) theorise on how the BSC can become a powerful interface for interrogation and can frame complex organisational decisions in a reflexive and context-specific manner. From this perspective, the rhetorical functioning of visualisations supports the reinvention of knowledge, thanks to the use of visual templates. Busco & Quattrone (2015, p. 1247) illustrate how

The BSC is not only a stable instrument of representation but also an active force [...] that relies on a visual schema to generate action. In doing so, the BSC makes users strategize [...] as they link figurative spaces, numbers, perspectives, and strategic imperatives.

The design of the BSC is not to be understood as a perfectly complete performance management system, which is an idea that “remains challenging, if not impossible, and would require nothing less than the expression of all the aspects of performance in quantitative terms” (Wouters & Wilderom 2008, p. 491). Instead, it can be interpreted as a visual performable space in which objectives, measures and indicators can be defined, interrogated, and appropriated by different users for diverse purposes (Busco & Quattrone, 2015, 2018a). This process of discussion and negotiation is important also thanks to its capacity of sparking tensions regarding what is valuable or desirable in a given scenario (see Stark, 2009):

Accounts of performance are critical because it is in discussions over the different metrics, images and words that can be used to represent performance that the [...] worth of things is frequently debated and contested (Chenhall et al., 2013, p. 269).

Building on these insights, Quattrone (2015b) proposes a theorisation of the potential roles of accounting as a ‘maieutic machine’. From his perspective, accounting not only can work as a post-hoc rationalisation device, as an ‘answer machine’ that offers fixed responses or as a political ‘ammunition machine’ to win arguments (Burchell et al., 1980), but can also be employed as a device to interrogate organisational scenarios and emergent issues. Similarly, Revellino & Mouritsen (2015), theorise on the possibility for the reinvention of knowledge that resides in the performativity of accounting calculations and their propensity to drift into unforeseen directions.

While ANT-inspired studies on the visual in accounting (e.g., Qu & Cooper, 2011; Busco & Quattrone, 2015; Thomsen & Skærbæk, 2018) offer valuable insights in the

understanding of the roles and operation of visual inscriptions, an ANT perspective can offer limited insights to a design approach to the study of visualisations. In fact, ANT's methodological commitment to a 'flat ontology' (Latour, 1999b) is at odds with a design framework that emphasises the designers' agency in shaping the practices of future use of organisational artefacts. In this sense, ANT's focus on translation and the tracing of association (Dambrin & Robson, 2011) is more suitable to explore how inscription devices unfold in practice *despite* the intended goals of the designers (Busco & Quattrone, 2015). Studies on inscriptions often tend to regard technologies of visualisation as *tabulae rasa* that are capable of bearing any given interpretation according to the specificity of their situations of use (Hutchby, 2001). In this sense, running the risk of overemphasising situational aspects, they stress that the fate of an artefact is entirely 'in the hands of others', thereby tending to neglect the artefacts' essentially material and technical aspects. In other words, placing their analytical focus on the representational incompleteness of inscriptions and underplaying the technical affordances of an artefact, they tend not to precisely account for how the materiality and design configurations are attributes that plainly matter in interaction.

Other studies on visualisations have accounted more precisely for some of the issues that are not addressed by the inscriptions' literature through a focus on sociomaterial practices. This is the case of Pollock & D'Adderio (2012) that, relying on an STS approach and the relational ontology of sociomateriality, illustrate how ranking devices and their visual instantiations are shaped by aesthetic ideals that produce 'beautiful pictures' through the technology of the 'Magic Quadrant'. Focusing on the 'format and furniture' of a visual technology, they theorise on the mediating and generative power of visualisations, showing "how IT markets can be as much a product of the affordances and constraints of ranking devices as any other (non-material) aspects of the ranking" (Pollock & D'Adderio, 2012, p. 565). Additionally, they shed light on the pragmatics of making visualisations work, and on how aesthetic criteria – such as parsimony and visual dynamic – constrain the use of visualisations⁵ (see

⁵ Pollock & D'Adderio (2012) contribute to a more thorough theorisation of how the construction of accounting visualisations places limits on designers, thereby supplementing the work by Lynch (1988) on the affordances of visual modes of presentation. According to Lynch: "The [*graph*] does not

Quattrone et al., 2013). These concerns are also explored by Pollock & Campagnolo (2015), who study how the ‘Magic Quadrant’ can enable cognitive processes such as *subitizing*, namely the capacity of making rapid and confident judgements based on quick observations of small numbers (Kaufman et al., 1949). They investigate how the interactional features (Pels et al., 2003) of business visualisations can frame organisational problem-solving, paying attention to how simplicity is connected to enabling the reader to be “informed at a glance of what may take several paragraphs to explain” (Morrison & Wensley, 1991, p. 141). Drawing from an analysis of the affordances of the quadrant, they emphasise how

Simplicity is different from simplification because it is not just about sacrificing detail and reducing features for the sake of clarity and visual manageability. Those producing matrices can increase as well as decrease the information portrayed (Pollock & Campagnolo, 2015, p. 104).

This aspect is of importance in the study of the design properties of visualisations, as it stresses how they can enable the perception of emergent properties in a non-reductionist capacity.

Quattrone (2017) addresses the issue of how project dashboard design can support decision-making in the management of organisations characterised by a high level of ambiguity and uncertainty by facilitating activities of scrutiny. He shows that dashboards can be designed to prompt wise judgement rather than perpetuating ideas of ‘mechanical objectivity’ (Porter, 1995). He shows that dashboards that aim to profit from the productive tensions among irreconcilable indicators can be designed according to the criteria of *in-tensions*, *di-vision* and *in-difference*. These criteria

necessarily simplify the diverse representations [...] that it aggregates. It adds theoretical information which cannot be found in any single micrographic representation [...]. [*In this sense, graphs can contribute*] visual features which clarify, complete, extend, and identify conformations latent in the incomplete state of the original specimen. Instead of reducing what is visibly available in the original, a sequence of reproductions progressively modifies the object’s visibility in the direction of generic pedagogy and abstract theorizing” (Lynch, 1988, p. 202-229).

intend to guide the design of artefacts that foster the visibility of opposing demands and expectations and are

Built on a series of dichotomic oppositions [...] which are conceived as logically opposed and geometrically proportioned: It embeds oppositions that lead to a division of space based on logical tensions (Quattrone, 2017, p. 599).

Combined, these studies provide valuable insights into some the critical issues that concern the design of visualisations. However, as it appears from the literature reviewed in this section, the focus of existent contributions has been mostly centred on how specific visualisations unfold – often in novel and unexpected ways – through their practice in specific contexts. As shown in the review of the extant literature, the growing field of the study of the visual in accounting has not tackled in detail the issue of how designers construct visualisations to support engagement with complex organisational phenomena. In this sense, very few studies “have provided insight into the makeup and minutiae” (Pollock & D’Adderio, 2012, p. 581) of the design of visualisations and the problems of their practical construction.

Hence, the construction of visualisations and the design criteria according to which they are realised remain an under-researched area of study. In this sense, Dambrin & Robson (2011, p. 430) argue that

Most proponents of performance measures, scorecards and dashboards appear undaunted by the problems of the practical construction or accessibility of the information sets that their chosen measures require: performance measurement lacks understanding of itself as a practice.

Similarly, calling for research on the exploration on the visual power of numbers, Busco & Quattrone (2015) argue that the study of the interactional features of visualisations is still underdeveloped and more research is needed to understand

How one should construct the representation rather than *what* one needs to represent, thus offering a method for creating order amidst various [...] perspectives and their possible connections (Busco & Quattrone, 2015, p. 1249).

This study aims to problematise and explore these issues relying on a design perspective, namely an approach that foregrounds the importance of studying the criteria according to which designers practically construct visualisations and employing theoretical lenses borrowed from design theory.

2.5. Concluding remarks

The purpose of this review of the accounting literature was to contextualise the current understanding of the visual within this field and outline the trajectories for development of this study. The chapter situated the concerns of this project within interdisciplinary research tradition and illustrated how the study of the visual is profoundly connected to the institutional, social, and political aspects of accounting. The chapter also offered a thorough survey of the literature on the operation of representation in accounting. In so doing, not only it investigated the limitations of the idea of correspondence in explaining representations, but also made a case for the importance of focusing on accounting's visual manifestations, which hold specific advantages compared to their analysis in discursive terms and as language games.

The review then turned to an exploration of the roles of the visual forms related to and inherent to accounting. Drawing from the literature on the visuals in annual reports, it showed the persuasive power of pictures in communicating intangibles and exerting influence over different audiences. Additionally, the historical importance of aesthetic criteria in the spread and popularisation of accounting technologies was discussed. Building on these insights, the chapter turned to experimental studies that shed light

into how the visualisation of accounting information may influence decision-making paying attention to how modes of presentation have an impact on the users of accounting information. Lastly, key contributions from interdisciplinary research on the visual in accounting were surveyed, and the design criteria according to which visualisations are constructed emerged as an under-researched issue that holds significant potentialities for development. The study seeks to contribute to these debates by exploring the design criteria that inform the design of accounting visualisations. To further conceptualise this research issue, the following theory chapter articulates a comprehensive design framework that is centred on the notions of affordances, visual conventions and visual literacy.

3. AFFORDANCES, VISUAL CONVENTIONS, AND VISUAL LITERACY IN THE DESIGN OF DATA VISUALISATIONS

3.1. Overview

Everything that we have around us has been designed. Anything that isn't a simple, untouched piece of nature has been designed by someone. The quality of that design effort therefore profoundly affects our quality of life. The ability of designers to produce effective, efficient, imaginative and stimulating designs is therefore important to all of us (Cross, 2011, p. 4).

As outlined in the previous chapters, this study investigates the question of how and according to which criteria designers construct visual artefacts that become influential in the management of complex and dynamic organisational settings. Before exploring how this happens in practice, it is necessary to establish on firm theoretical grounds an epistemology of design that enables to connect design concerns with the ontological and cultural status of artefacts and technologies of visualisations. To achieve this goal, in section 3.2. this study takes inspiration from Simon's (1996) *The Sciences of the Artificial* to develop a theoretical framework for the design of visual artefacts that overcomes Simon's reductionism while retaining the advantages of his purposeful and functional understanding of design. Since any design is an instantiation of theories about material influences on behaviour, in section 3.3. I contend that a precondition for the development of a theory of design is identifying an epistemologically compatible theory of perception. For this reason, I critically discuss J. J. Gibson's ecological theory of perception focusing on his theorisation of the concept of affordances as actionable properties of the environment. The notion of affordance travelled from the research domain of the psychology of perception to neighbouring fields, such as design theory and STS; these contributions are critically assessed focusing mainly on Norman's (2013) notion of perceived affordances and its conceptual implications. Section 3.4. discusses the preconditions for detecting and engaging with affordances, paying attention to the demarcation of affordances and

cultural constraints. Additionally, this section explores how individuals learn to engage with visual information. Specifically, the notions of visual literacy and aesthetic knowledge are discussed and linked with the theoretical concerns of the framework. Section 3.5. reflects on the roles of visual conventions, namely the features of the visual language deployed by designers in the creation of organisational artefacts, which perform fundamental roles in supporting (or hindering) communication and engagement with visualisations. Lastly, section 3.6. links the theoretical framework with the notion of sociomateriality and further discusses how affordances and visual conventions structure engagement with visual artefacts. In so doing, the last section also illustrates the ontological and epistemological positioning of this thesis.

3.2. Simon's *The Sciences of the Artificial* as a philosophy and science of design

According to Herbert A. Simon (1996, p. 111), one of the first contemporary proponents of a philosophy and science of design, at the highest level of generality, “everyone designs who devises courses of action aimed at changing existing situations into preferred ones”. Simon’s (1996) work – published in its first edition in 1969 – illustrates the potential and pervasiveness of design as an approach to analysing, structuring and organising complexity, and outlined agenda setting trajectories for the fields of behavioural psychology, artificial intelligence, administrative sciences, and design studies. Simon’s (1996) theorisation of the functions and scope of the design discipline and his concern with developing artefacts along with assemblies of actions is possibly the most ambitious and comprehensive effort in establishing and justifying the importance of design in the social sciences. This chapter, starting from a critical discussion of Simon (1996), positions the theoretical concerns of this project with different research traditions in the study of design to set the background for the detailed articulation of the theoretical framework.

Simon (1996) grounds his theory of design on explicit ontological considerations. He claims the existence of a foundational difference between ‘natural’ and ‘artificial’

phenomena. In his theorisation, the natural sciences relate to how things *are*, in purely descriptive terms. Artificial phenomena, on the other hand, are synthesised by human beings; thus, they are embedded in performative considerations that relate to *functions*, *goals*, and *adaptation*. According to Simon, artefacts are not apart from nature, but they are different insofar as human aims and intent shape them. Within this background, Simon poses the question if there can be a science of artificial objects and phenomena. His answer is positive, and the science of the artificial is a *science of design*, that is “a body of intellectually tough, analytic, partly formalizable, partly empirical, teachable doctrine” (Simon, 1996, p. 113).

From his perspective, artificial things can be described in terms of imperatives, and the science of design is grounded on the notion of the *interface*:

An artefact can be thought as a meeting point – an ‘interface’ – between an ‘inner’ environment, the substance and organisation of the artefact itself, and the ‘outer’ environment, the surrounding in which it operates. If the inner environment is appropriate to the outer environment, or vice versa, the artefact will serve its intended purpose (Simon, 1996, p. 6).

The creation of an interface occurs through the designer’s activity of insulation of the inner system from the environment, which aims to crystallise relationships that are to a significant extent invariant between the inner environment and the intended goal (see Simon, 1964). It is apparent that at the heart of Simon’s theorisation there is a functionalist understanding of design:

The designer is concerned with how things ought to be – how they ought to be in order to attain goals and to function. [...] The outer environment *determines* the conditions for goal attainment (Simon, 1996, pp. 5-6-11, emphasis added).

From this viewpoint, the material outcome of the design activity is something that mediates the demands and constraints of the outer environment through a set of

precisely articulated operative principles in its inner environment. Hence, good designs are the ones that are effectively and efficiently made to *adapt themselves* to their environment.

In light of these considerations, Simon's theoretical positioning is based on a realist epistemology grounded on the interpretation of complexity as based on the near decomposability assumption, which is reductionist in nature and does not question the power of declarative logic in making statements of causality⁶. Simon's (1996) interest lies in design problems from the perspective a decision-maker that faces an environment that is conceptualised as a given to which the manager must adapt the organisation. Simon's discussion of design and his language resembles the epistemological assumptions of Wittgenstein's (1922) theory of picture representation and his understanding of the importance of placing a continuous effort in the reconciliation of ambiguity through the progressive clarification of a design (or a statement, in Wittgenstein's case) and its situation of use.

However, in some later chapters, Simon (1996) explores issues that relate to higher-order types of designs, at the social system level (e.g., policymaking). These types of phenomena are deemed significant because "artificiality is interesting principally when it concerns complex systems that live in complex environments" (Simon, 1996, p. ix). When dealing with less definable phenomena, Simon's (1996) language changes, admitting the existence of the symbolic dimension of language, its unavoidable ambiguity, and the role of designers in shaping the environment they perceive. When approaching these complex design situations, Simon makes a theoretical move that may be seen as antithetical to the core philosophical position of

⁶ According to Simon (1996), the principle of 'near decomposability' is a structural property of the architecture of complexity that offers evolutionary advantages that are beneficial to both natural and artificial systems (see Langlois, 2002). As Garud et al. (2008, p. 353) argue, "decomposability refers to the partitioning of a system in such a way that the interactions of elements within a subassembly are greater than the interactions between them". This concept has also been influential in the study of how complex system can be decomposed into functional modules. In the design of modular systems, each module works as a 'black box' that engages through standardised interfaces with other black-boxed modules (see Rosenbergh, 1982).

his book. In fact, he claims it is necessary to design “without final goals”, because “the idea of final goals is inconsistent with our limited ability to foretell or determine the future” (Simon, 1996, pp. 162-163) and the emergent properties of complex settings.

Simon’s recognition of the impossibility of fully formalising the design activity in terms of statements of causality is tied to the dynamic characteristics of the higher-order social phenomena he intends to tackle in the final sections of the book. To apply the ‘science of design’ to such phenomena, it is necessary to acknowledge that complicated organisational entities could be conceptualised as having

Many things happening at once. Technologies are poorly understood; alliances, preferences, and perceptions are changing; problems, solutions, opportunities, ideas, people, and outcomes are mixed together in ways that make their interpretation uncertain and their connections unclear [...]; solutions seem to have only modest connection to problems; policies are not implemented; decision makers seem to wander in and out of decision arenas (March, 2008, p. 36).

The idea of designing without final goals appears to be a precondition to employ design to engage with environments characterised by the features outlined above by James G. March. It is when dealing with the emerging complexity of dynamic settings that the reductionism that characterises Simon’s (1996) approach becomes especially problematic. Simon’s belief in the possibility of reducing ‘superior’ manifestations of behaviour to their mechanistic components becomes conceptually inadequate in tackling the issue of designing without final goals. The necessity of such an open-ended application of the design framework represents the theoretical limit of Simon’s seminal philosophy of design.

However, there is another important aspect of *The Sciences of the Artificial* which can constitute the basis for the exploration of the emergent challenges of the design activity

and the theoretical foundation of the design epistemology. As Boland argues in a critical discussion of Simon's approach to design:

Developing an awareness of one's own vocabulary and its impact on one's design work can make design an ideal vehicle for creating dialogue across specialized professions. As Simon argues, it can provide a common ground for diverse professionals to engage in discussions across the divide of their disciplines about the qualities of their design vocabularies, the creative experience of designing, and the criteria for making design judgments, all of which are sorely needed in our highly specialized world (Boland, 2004, p. 107)

It is precisely in the development of this common ground that resides the core of the importance of Simon's (1996) work. As the cornerstone for a theory of design applied to administrative sciences, *The Sciences of the Artificial* is a constant reference point that has shaped and informed research approaches to design that are characterised by profoundly different epistemological assumptions, some of which are more fit for purpose in explaining and grounding the necessity of designing without final goals as a fundamental aspect of a theory of design.

3.2.1. Designing without final goals

Several accounts of the very notion of 'design theory' have been proposed by scholars in different research fields, such as design studies (e.g., Margolin, 1999; Love, 2000), engineering (e.g., Petroski, 1985; Cross, 2011), management studies (e.g., Van Aken, 2004; Barzelay & Tomphson, 2010), information systems (e.g., Gregor & Jones, 2007), and art theory (e.g., Margolin, 1989; Vitta, 1989). The plethora of perspectives in the design research field (broadly defined) seems to suggest that there cannot be a unifying design science, such as the one envisioned by Simon, because there is incommensurability of viewpoints in design research (Sargent, 1994; Love, 2000). As In the research discourse on design there is a longstanding debate over the very definition of discipline. Such definitions range from Simon's (1996) reductionist account to perspectives such the one advocated by Margolin (1989) of design as a

creative form of practical art or communication, to the positions such as Petroski's (1985) who interprets design as the purposeful activity of disassembling and reassembling nature.

At a high level of generality, the move from Simon's approach aimed to overcome the limitations of a design framework that was not effective in accounting for and tackling its social context (Dilnot, 1982; Love, 2000). While this point is indeed the weakest link in Simon's design philosophy, theorists who attempted to overcome this issue often fell for the paradoxes of deconstruction to the point that they diluted any distinctive features of the conceptual core of a rigorous approach to design in the domain of the social sciences. These positions tend to advocate for the (even more problematic) impossibility of any preferred way of doing design, as well as claiming that, in a pluralistic society, no intended meaning can possibly be conveyed through the outcome of the design activity (Margolin, 1989). From these postmodernist perspectives, design is a *culture* that links

The totality of disciplines, phenomena, knowledge, analytical instruments and philosophies that the design of useful objects must take into account, inasmuch as those objects are produced, distributed, and used in the context of economic and social models that are even more complicated (Vitta, 1989, p. 31).

However, in the development of a design approach to the social sciences which aims to retain the purposeful nature of the discipline in transforming existing conditions into preferred ones, the perspectives outlined above deconstruct the fundamental functional objective of the design activity, making of it a directionless praxis without a defining conceptual core. In this sense, these postmodernist perspectives not only abandon any normative ambition of a design framework, but they conflate the fact that there is an almost infinite ways of looking at a finite set of objects with the assumption that all such interpretations of design artefacts are potentially of equal functional and interactional validity. While this hermeneutic view correctly stresses the multiplicity of relevant interpretations of situations and artefacts, it settles too easily for infinite

subjectivity in the assessment of design objects. This is not only theoretically problematic, but from an epistemological perspective it does not account for how the perceived function of an object *constrains* its interpretation and use in practice (Gibson, 1986; Clark, 1993, 2008). Accordingly, such perspectives implicitly deny that perception is designed for action (Nöe, 2004) and are hence are guided by a disembodied theory of perception.

In the light of these considerations, this chapter outlines an approach to design that retains the *raison d'être* of Simon's (1996) perspective while avoiding the theoretically problematic consequences of his reductionism. In this sense, to operate a viable mediation among the approaches discussed in this section, I draw from literature in neighbouring research fields that can be mobilised to retain the *positive* dimension of a design approach to the social sciences without falling in the paradoxes of deconstruction that characterise some of the postmodernist perspectives mentioned earlier. To achieve this balance, I rely on approaches that contextualise design problems with their cultural and organisational context, without losing sight of the functional and problem-solving oriented nature of design. One of such perspectives is Murray's (2012) approach to interaction design as a cultural practice, according to which

To see any artefact as part of a culture is to understand how it becomes meaningful through the social activities, thoughts, and actions of the people who engage with it. [...] The humanist designer aims to see as much as the larger web of meanings as possible in order to understand the context and connotations of particular design choices (Murray, 2012, p. 1).

In this study, when possible, the human actor(s) engaging with design artefacts will be referred to as *interactors*. As Murray (2012) argues, such actors in the design and human-computer (HCI) interaction research tradition tend to be simplistically referred to as *users*⁷. The term 'users' suggests that the artefact in question has the status of a

⁷ The term 'user' is often understood as a figuration created by the designers with the objective of developing understanding of the 'practices of future use' (Bjørn & Østerlund, 2014). It is understood as

mere tool, which is entirely controllable and has no agency. The term (human) interactor, on the other hand, refers more inclusively to

Someone who is not so much using a device as acting within a system. [...] By designing for interactors rather than users we remind ourselves of the larger context of design beyond mere usefulness (Murray, 2012 p. 11).

Consistently, the approach I aim to develop not only problematizes the interactor, but also the context of the design activity. The settings this approach aims to tackle are those characterised by complexity, ambiguity, and emerging properties. As Orlikowski (2004, p. 94) argues, “dealing with emergence requires designers and managers to understand their designs in relation to those who will enact them in practice”, in connection with the specificities of their contexts. In complex and dynamic settings, there is no clear separation between the inside and the outside, the inner and outer environments theorised by Simon, but there is an always unfolding and emerging network of associations. In these intertwined contexts, problems are fuzzy, ill-defined and solution-dependent, preferences are fluid and solutions emerge in interaction. In tackling these settings, the emphasis on *completeness* and *decomposability* that characterizes much of the (functionalist) discourse on design in management studies (see Romme, 2003; Van Aken, 2004) is likely to result in the foreclosure of future options and opportunities (Hedberg et al., 1976; Weick, 2004). That is because complex and dynamic settings do not have “a clear and stable boundary between the entity being designed and the context for which it is being designed” (Garud et al., 2008, p. 352).

To tackle the dynamism of complex settings, the reductionist approach to design that requires complete and faithful representations of design problems is highly unlikely to work. In such contexts,

a figuration because: “The user’ singularizes what is actually a multiplicity and fails to differentiate actors with very different relations to a given artefact” (Suchman, 2007, p. 188).

System boundaries are often unclear and user preferences are both heterogeneous and evolving. As a result, the goals and purpose of the design are likely to remain a continually moving target (Garud et al., 2008, p. 354).

In this sense, design approaches that are open and afford interpretive flexibility are more promising, in that they require the involvement of the user in the process of the adaptation of a design artefact to the context. An incomplete design cannot give results without questioning and adaptation. From this perspective, Simon's (1996) idea of *designing without final goals* acquires a different, and more radical meaning as it supposes the involvement of the interactors and the development of a narrative logic⁸ that redefines the agency of the decision maker (Orlikowski, 1992, 2007). From this perspective, design artefacts and visualisations can become tools for interrogating possible futures and, drawing upon the limits and discrepancies of the representation itself, allow reaching decisions that are context-dependent.

This section sought to contextualise different approaches to design and outlined the approach taken in the development of this framework. To ground the framework and discuss its underpinnings it is necessary to explore what Rudolf Arnheim conceives of as the core of any design framework, namely its implied theory of perception:

Designing always involves the solution to a problem, the carrying out of a task, and, therefore, the image unfolding in the mind always refers to a goal image. This final objective manifests itself at some degree of abstraction. [...] The goal image may be highly intellectual [...] But because all abstract thinking relies on some perceptual referent, even the most abstract theme is tied from the beginning to concrete images. These images supply the designer with the primary nucleus from which the actual structure develops (Arnheim, 1993, p. 16).

⁸ A narrative logic “operates on the basis of a narrative’s internal coherence and its external coherence with the [*interactor’s*] existing knowledge. In providing designers with the interpretive flexibility required to generate contextualized solutions and to imagine what might be, the narrative can help coordinate distributed activities across time and space” (Garud et al., 2008, p. 366).

The next section articulates the theory of perception that lies at the core of this design framework: The theory of affordances.

3.3. Grounding a theory of design on a theory of perception

3.3.1. The theory of affordances

This section critically discusses Gibson's theory of affordances and illustrates the reasons why this notion is instrumental in the development of a framework for the design of data visualisations. The notion of affordance originally was coined in the domain of perceptual psychology by J. J. Gibson (1986). Gibson was a neopragmatic scholar of the ecological tradition who developed a non-mediated and action-oriented theory of visual perception, which was articulated based on the hypothesis that we perceive to operate in the environment (see Nöe, 2004). Gibson's theory challenged a central assumption of traditional approaches to perceptual psychology, which tended to treat perception in a non-contextual manner, emphasising how actors perceive specific aspects of their environment without focusing on the environment as such. According to Gibson (1986), perception is designed for action, and the perceivable possibilities for action are the affordances of the environment. Such *action possibilities* or *actionable properties* are relationship constituted between an interactor and the environment and are conceived as directly perceivable, not inferred from sensory clues⁹. In this sense:

Affordances of the environment are in a sense objective, real, and physical, unlike values and meanings, which are often supposed to be subjective, phenomenal, and mental. But an affordance is neither an objective property nor a subjective property. [...] An affordance cuts across the dichotomy of

⁹ One of the examples used by Gibson to illustrate the notion of affordance: "An elongated object of moderate size and weight affords wielding. If used to hit or strike, it is a *club* or *hammer*. If used by a chimpanzee behind bars to pull in a banana beyond its reach, it is a sort of *rake*. In either case, it is an extension of the arm. A rigid staff also affords lever age and in that use is a *lever*. A pointed elongated object affords piercing – if large it is a *spear*, if small a *needle* or *awl*" (Gibson, 2014, p. 125).

subjective-objective and helps us to understand its inadequacy. It is equally a fact of the environment and a fact of behaviour (Gibson, 2014, p. 121).

In this sense, affordances are “*taken with reference to an observer but not properties of experience of the observer*” (Gibson, 2014, p. 129). The condition of possibility of affordances is the external environment, an environment which contains different interactors with limitless opportunities to engage with it. Although the identification of an affordance might depend on the specific needs of an interactor, the affordance of something does not change in accordance to with a change of needs of such interactor. The affordance is an invariant property of the relationship that is always there to be potentially perceived and acted upon.

It is important to emphasise the significance of the epistemological implications of the theory of affordances within its original ecological framework. Gibson’s (1986) position goes against cognitivist and functionalist approaches, according to which – in general terms – thought and action can be explained as self-sufficient rules and representations. Contrariwise, from an ecological perspective, “no environment is ever fully created; it is always undergoing creation. It is, as it were, ‘work in progress’” (Ingold, 1992, p. 50). The notion of affordance is conceptually distant from the physicalist ideal of the ‘ideally isolated system’ (see Whitehead, 1926) which is functionally isolated from its setting:

To [*conceptually*] *isolate* affordances and actions [...], in the cause for analytical simplicity, is to eliminate perhaps the most salient feature of action, its embeddedness and open-endedness (Costall & Leudar, 1996, p. 105).

To consider a set of affordances as fixed, namely as offering preconditions for corresponding sets of actions, is to crystallise what is intended to be understood as an interactional process. It is in this sense that Gibson’s mutualist position acquires its meaning: “Affordances are properties take with reference to the observer. They are neither physical nor phenomenal” (Gibson, 2014, p. 135). Affordances as relationships

do not arbitrarily restrict the opportunities for engagement with an object or artefact, as perceiving an affordance does not imply the classification of an object. For instance, the fact that a glass bottle is a container does not imply it cannot be a weapon, as affordances as relationships are not inconsistent or mutually exclusive. In fact:

The differences between them are not clear-cut, and the arbitrary names by which they are called do not count for perception. [...] The theory of affordances rescues us from the philosophical muddle of assuming fixed classes of objects [...]. As Ludwig Wittgenstein knew, you cannot specify the necessary and sufficient features of the class of things to which a name is given. They have only a 'family resemblance'. But this does not mean you cannot learn how to use things and perceive their uses. You do not have to classify and label things in order to perceive what they afford (Gibson, 2014, p. 126).

This section outlined the conceptual core of the notion of affordance in Gibson's (1986) ecological framework. The next section explores how the theory of affordances travelled to neighbouring research fields, focusing on developments that occurred in design theory and STS.

3.3.2. The theory of affordances in other research fields

Gibson's theory of affordances was impactful in the fields of psychology and philosophy of perception and currently is influential in design theory and interaction design, human-computer interaction, data visualisation, and visual communication (see Norman, 2013; Gaver, 1991; Ware, 2012). Gibson (1986) knew the explanatory potential of affordances for design and, although he did not explore in detail such issues himself, he outlined trajectories for their development. Affordances offer

The possibility of a new theory of design. We modify substances and surfaces of our environment for the sake of what they will afford, not for the sake of creating good form as such, abstract forms, mathematically elegant forms, aesthetically pleasing forms (Gibson, 1986, p. 404).

However, the application of Gibson's notion of affordance to the study of design and information visualisation required theoretical modifications due to several limitations of the theory in its original formulation. These problems emerge especially if Gibson's theory is taken literally¹⁰. As Ware (2012) highlights, even if the perception of the environment is direct, nowadays the visualisation of information often occurs in a mediated fashion, for instance through digital interfaces. In this sense, direct perception is not the most suitable concept to explore the many layers of processing that occur between the data and its visual presentation. Accordingly, one could argue that

There are no clear physical affordances in any graphical user interface. To say that a screen button 'affords' pressing in the same way as a flat surface affords walking is to stretch [Gibson's] theory beyond reasonable limits (Ware, 2012, p. 19).

The meaning and interactional possibilities of digitally-mediated interfaces seem to be inextricably connected to a learning process of conventional features of information visualisation (Ware, 2012; Norman, 1999).

The theoretical formulation of the notion affordance was further developed and expanded to increase its potential scope of applicability to the study and practice of design. The concept of affordance more loosely defined and detached from the Gibsonian theory of perception proved to be extremely useful for information visualisation. Donald Norman, a design theorist and cognitive scientist, further developed affordances illustrating how they can also be understood as merely perceivable in his 1988 bestseller *The Psychology of Everyday Things*¹¹. From his

¹⁰ The following discussion considers problems in the application of the original formulation of the theory affordances to the domains of design and management studies. Issues in Gibson's theory of the psychology of visual perception go beyond the scope and interests of this thesis.

¹¹ In *The Psychology of Everyday Things* Norman was ambiguous in his conceptualisation of affordances. This caused significant but mostly misguided debates in the human-computer interaction and design research community (Norman, 1999). Norman expanded and clarified his theoretical

perspective, affordances are the relationships between the (perceived or physical) properties of an object and the capabilities of an interacting agent that determine how the object can be used. Norman (1999, 2013) couples the notion of affordances with that of signifiers to expand their explanatory potential and applicability. Signifiers are the signalling components of affordances:

Affordances determine what actions are possible. Signifiers communicate where the action should take place. [...] Signifier refers to any perceivable indicator that communicates appropriate behaviour to a person (Norman, 2013, p. 14).

Signifiers¹² indicate what a design ‘is for’ (Norman, 2013), and they can be as powerful as functional specifications in the domain of interaction (Gaver, 1991) as they signal how certain designs should be approached. In this sense, signifiers are often the precondition of successful interaction. Signifiers, such as the sign ‘pull’ on a door, are important communication devices that provide valuable clues for interaction in context. Affordances can be perceivable or invisible, and sometimes signifiers are the perceived affordances, yet they are different in that signifiers *must* be perceivable to function. One of the advantages of the notion of perceived affordances, especially if applied to the study of digitally mediated interfaces, is that “perceived affordances are sometimes useful even if the system does not support the real affordance” (Norman, 1999, p. 40) – this is evident, for instance, in the case of computer icons. Norman’s point of departure from Gibson’s original formulation may seem subtle, yet it has profound implications about the epistemology of affordances.

position in the 2013 re-edition of his best seller: *The Design of Everyday Things: Revised and Expanded Edition*. In this study, I refer only to Norman (2013).

¹² Norman (2013) uses the notion of signifier to refer to any perceivable indicator of an object that aims to transmit to the interactor relevant criteria for effective engagement. Hence, the term has a different, narrower and more functional meaning from that in philosophy of language.

Thanks to Norman's formulation, the notion of affordance could travel more lightly, and this led to its prolific application, for instance, in STS. STS scholars further theorised the properties of affordance with an emphasis on their functional and relational characteristics (see Pels et al., 2003; Burri & Dumit, 2008). Affordances, in this stream of studies, are theorised as being *relational* as they may differ for an object in different contexts and are *functional* since they enable and constrain interaction, thereby "shaping the conditions of possibility associated with an action" (Hutchby, 2014, p. 87). This enabling and constraining activity occurs at the interface between design and interactor in a situation of use, in which affordances induce specific forms of usability thanks to the material configuration of the object to which they refer to. Thanks to their relational nature, they do not arbitrarily restrict the domain of interactions possibilities that imaginative users can develop (see Stark & Paravel, 2008; Kaplan, 2011), and they can always be approached otherwise. In the light of that, perceived affordance appeal to both the material aspect of the design of objects and artefacts, as well as to the idiosyncratic domain of interpretation (see Vitta, 1989; Boland, 1989), without specifying a definite statement of causality in the outcome of the interaction.

Affordances are functional-relational aspects that shape without determining interactions with an artefact (Hutchby, 2001, 2014). They can be employed to detail how the design features of visualisations can pre-script and pre-form interactions (Kaplan, 2011; Jarzabkowski & Kaplan, 2015), while leaving the question on the goal of an action interpretively ambiguous and to be negotiated in each context. The pre-scribing and pre-forming function of affordances are not "structures that are directly deterministic but processes of constrained opportunities" (Stark & Paravel, 2008, p. 33; see Kornberger, 2017), that emerge from the engagement with the visual-material configuration of an artefact. The advantage of mobilising this notion for the study of visualisation resides in the explanatory power it attributes to material features of artefacts, without falling into reductionist assumptions: "The term affordance crosses back and forth between materiality and design [...] and helps to understand the capacities and limitations of materials" (Levine, 2015, p. 9).

Given their interactional nature, affordances have a potential mode of being that helps to understand the possibilities and limitations of different ways of visualising information. However, the potential mode of being of affordances makes their identification partly contingent on contextual and conventional factors that characterise a given culture, community, profession or organisation (Burri & Dumit, 2008), and go beyond the functional specifications of an artefact (Sengers & Gaver, 2006). Hence, the presence of design features is not sufficient to foster interactional possibilities with a specific way of visualising information. For the study of design artefacts and visualisations, affordances are therefore an insufficient theoretical lens without the support of the notion of conventions.

3.4. Engaging with affordances

3.4.1. Affordances and constraints

The previous sections discussed the significance of affordances in a framework for the design of visual artefacts and illustrated the limitations of the concept in providing a comprehensive theorisation of interactional possibilities. As Norman (1999) noted, it is incorrect to claim that a graphical icon on a screen, for instance, ‘affords clicking’. The fact that an interactor can ‘open’ a folder by clicking on the icon does not relate to the affordances of the icon as such. Instead, it relates to the conventional dimension of the usability and understandability of a system (Norman, 2013). This conventional dimension, which can be manipulated by the designers independently from the domain of the *actual* affordances, is connected to the symbolic aspects of interpretation and communication – a domain that can serve design purposes only if understood by the interactor. In this sense, one could argue that “the designer cares more about what actions the user perceives to be possible than what is true” (Norman, 1999, p. 39). Hence, it is important to differentiate among affordances and conventions to avoid confusion among their implications.

A problematic aspect of the research conversations on this topic is that “much of the discussion about the use of affordances is about really addressing conventions [...] or cultural constraints” (Norman, 1999, p. 40). This confusion is not only to be identified in research debates among design scholars, but also in the accounting and management literature that relies on hermeneutics (e.g., Boland, 1989), visual inscriptions (e.g., Thomsen & Skaerbaek, 2018), and visual rhetoric (e.g., Quattrone, 2017). These approaches, that emphasise how visualisations unfold *despite* the intentions of the designers (Busco & Quattrone, 2015) and stress the infinite possible interpretations of artefacts, tend to neglect the technical and design core of such objects because they inadvertently treat conventional aspects (that are inherently a property of a setting or situation) as if they were material affordances of said objects. This confusion, as Feldman & Pentland (2008) argue, is also connected with how studies on translation and inscriptions often fail to account for the materiality and technical affordances of organisational artefacts. The goal of this section is to contextualise affordances and constraints and to discuss demarcation criteria that are relevant for the design of visualisations.

Norman classifies the conventional dimensions as belonging to the domain what constrains interaction, and such constraints can, in turn, be physical, logical and cultural (Norman, 1999). Physical constraints are connected to the real affordances of an artefact; an example of a physical constraint is the impossibility of moving the cursor outside the screen of a digital interface. Logical constraints are related to the use of reasoning in choosing among alternatives; they represent the process whereby users can abduct the actions required of them in the engagement with an interface. Logical constraints are what makes a design model visible and understandable. Lastly, cultural constraints are conventions that are shared by a profession, community, organisation or cultural group. The cultural aspect of conventions implies that “there is nothing inherent in the devices or designs that requires the system to act in [*a specific*] way” (Norman, 1999, p. 41).

Constraints are not only factors that inhibit interaction but are also the prerequisite for achieving a successful design, as constraining “enables effective design by reducing the potential for error and clarifying the possibilities for action” (Vandenbosch & Gallagher, 2004, p. 199). Constraints, in connection with affordances, illustrate an existing tension between the material features of artefacts and the language that needs to be understood to engage with them. Information visualisations, despite having affordances that emerge from their visual-material features, are also arbitrary. One visualisation might ultimately be as good as another, and what can make the difference in interaction is the mastery of a visual code that designers deploy, and users know how to interpret. In the identification of a framework that reconciles visual-material features with their symbolic meaning, it is necessary to find a viable mediation between *arbitrary* (or *conventional*) symbols and those that can be defined as *sensory* (Ware, 2012).

The issue if visualisations are conventional or perceptual symbols with specific properties was subject to a significant investigation (e.g., Kennedy, 1974; Pearson et al., 1996). The two opposite positions are that which claims the purely conventional nature of visualisations – according to which “the limits of any design [*are understood as*] culture-bound: All successful designs rest solidly on specific precedents” (Ferguson, 1999, p.15) – and that which contends that the understanding of certain aspects of pictures is not only a learned skill¹³ (Pearson et al., 1996). The opposition of these perspectives becomes even more evident about non-pictorial visualisations (Bertin, 2011), which represent the area of interest of this study.

3.4.2. Sensory and arbitrary visualisations

¹³ Studies have shown how children that have never been exposed to pictures are nonetheless able to call visualised objects by their name (Hochberg & Brooks, 1962). Similar studies showed that readers need little experience to associate effectively a realistic image with its referent (see Perkins, 1980).

Neither the strictly sensory nor the purely conventional understanding of visualisations are sufficient in ensuring a comprehensive framework for information visualisation. Instead, it is paramount to identify a theorisation that enables to retain the explanatory power of both positions:

The word *sensory* is used to refer to symbols and aspects of visualizations that derive their expressive power from their ability to use the perceptual processing power of the brain without learning. The word *arbitrary* is used to define aspects of representations that must be learned, because the representations have no perceptual basis (Ware, 2012, p. 9).

Sensory visualisations have several characteristics. They ensure a degree of understanding without learning – for example, the perception and imagination of a 3D shape out of a 2D visualisation (Cross et al., 1997). They are resistant to alternative denotation, because they may persist even in the case in which the subject knows they are illusory (Ware, 2012). They are sensory immediate because some of their features are processed in fast and direct fashion (Cotgreave et al., 2017). An example of immediate sensory attributes is colours, which are pre-attentive attributes, namely visual features that the human brain processes at a glance in milliseconds before paying attention to other visual inputs. Such attributes include colour difference, colour (hue), size, orientation, length, width, shape, curvature, added marks, colour value, position, and spatial grouping (Cotgreave et al., 2017). Lastly, they are characterised by cross-cultural validity, which refers to the capacity of specific visual codes to be understood across cultural and professional boundaries without explanation.

Contrariwise, arbitrary – or conventional – codes tend to be hard to learn, easy to forget, embedded in cultural and professional applications, and persist thanks to how they are embedded in the way people think about specific problems (Ferguson, 1999). Additionally, as symbol systems, arbitrary representations can be formally powerful. This is the case of what, in design research, are called nonreferential functions. Nonreferential functions are conventions that suggest broad categories of meaning without aiming to create a close correspondence between image and referent (Ashwin,

1984). In this sense, nonreferential conventions play different roles in pre-forming interpretation and interaction, ranging from the rhetorical structuration of a document template to building a specific visual ethos (Kostelnick, 1988, 1996), or by merely stimulating and attracting attention emphasising aspects or features. Additionally, arbitrary and nonreferential conventions

Perform metadiscourse functions: Rather than adding new information, they structure or emphasize existing information, they give it a certain tone or level of formality, or they certify its authenticity (Kostelnick & Hassett, 2003, p. 176).

It appears that both the sensory and arbitrary dimensions can be understood as factors that complement each other in interpretation and meaning-making (Kazmierczak, 2003). The coupling of these perspectives enables the identification of design features whose expressive power is grounded on visual characteristics that build on a good fit between information visualisation and the visual sensory system – in an approach similar to that advocated by Simon (1996) – without losing track of the fundamental importance of conventional aspects and the learning processes required to master them.

It is essential to keep in mind that the perceptual and conventional domains are intertwined and attempting to draw a precise line to separate them could cause approximations that would ultimately be unilateral. Accordingly, one could argue that

Oftentimes, conventions capitalize on perceptual principles, so deciding what lies within the domain of convention and what within the domain of perception, or which prevails over the other, poses problems (Kostelnick & Hassett, 2003, p. 52).

The fuzziness of the boundary between what is conventional and what it is not¹⁴ can be capitalised upon by trying to design artefacts that build on the characteristics of the human visual information processing system in combination with an understanding of the cultural preconditions for interpretation and understanding.

3.4.3. Visual and aesthetic literacy

Before exploring the domain of visual design conventions, it is essential to discuss some fundamental preconditions for interactors to understand and engage with the formal, informal and context-specific workings of conventional elements that characterise artefacts. This precondition is visual literacy, which can be broadly defined as an interactor's awareness and knowledge of the conventional aspects that shape how visual artefacts are created and understood in a setting¹⁵ (Messaris & Moriarty, 2005). Given the always increasing reliance on data visualisations and digital interfaces in organisations, eminent scholars argue that “visual literacy will begin to be a matter of survival, especially in the workplace” (Kress & van Leeuwen, 2006, p. 3). In the light of these considerations, visual literacy needs to be further unpacked since it represents a fundamental aspect of the study of visual artefacts and practices, especially in professional domains associated with project management (e.g., Whyte et al., 2007), strategy (e.g., Jarzabkowski & Kaplan, 2015), engineering (e.g., Ferguson, 1999), and accounting (e.g., Quattrone, 2009) that are characterised by significant reliance on visual technologies.

¹⁴ An important early modernist effort in developing ‘pure designs’ that did not rely on conventional aspects was put in place by the Bauhaus. Otto Neurath's isotope system, for example, was based on a positivistic philosophy of perception which led the designer to believe in the possibility of removing the mediating influence of conventions through the application of perceptual categories that were considered universal and empirically proven (see Wolfe, 1981). Similarly, Gropius developed Bauhaus curricula starting from the methodological principle of ‘starting from zero’, a systematic effort to remove conventional design influences from the past, to unveil the power of fully articulated and internally consistent design criteria (Wolfe, 1981).

¹⁵ As Messaris & Moriarty (2005, p. 481) show, visual literacy is a learned skill that has been theorised and defined in different ways, such as: An aptitude for visual communication, visual thinking, and visual learning (Seels, 1994), a set of competencies and strategies of communication (Dondis, 1973), a set of skills-oriented learning objectives.

The linguistic analogy implied by the term ‘visual literacy’ is however potentially misleading. Verbal language is characterised by a vocabulary that illustrates how each linguistic object is related to another. This is the syntagmatic dimension that focuses on the positioning of an element in a broader statement (Saussure, 2011), articulated according to a syntax, which is concerned with signs as such and their formal requirements of association. Verbal language can be regarded as one-directional and one-dimensional (Saussure, 2011; see Hayoun, 2018), whereas visual language does not have such linear indicators since the meanings of visual arguments are always implied and synthesised (Goodman, 1978). For instance, if one visualisation is located next to another one, it is up to the viewer to abduct a possible connection. In this sense, ‘readers’ of visualisations can ‘go on’ – in Wittgenstein’s sense (1958) – only when they have found a familiar pattern, or an acceptable alteration of one (family resemblance), which fits while exceeding the cases given (Goodman, 1978). Accordingly,

While speech is based on the logic of time, (still) image is based on the logic of space. It uses the affordance of the surface of a (fragmented) space. [...] In image, meaning is made by the positioning of elements in that space; but also by size, colour, line and shape. [...] Words can be ‘spoken’ or ‘written’; images are ‘displayed’. [...] Meaning relations are established by the spatial arrangement of entities in a framed space and the kinds of relation between the depicted entities (Kress, 2009, p. 82).

What follows from the quote is that visual language should not be reduced to the linearity of interpretation afforded, at least in theory, by verbal language. To provide a compelling theorisation of the operation of visual literacy in the engagement with artefacts, it is essential to keep in mind that:

Like a chemical reaction, the visual signs are interdependent: Different combinations alter the visual effects of individual signs, which collectively alter the meaning of the message. Because these combinations are bound perceptually and rhetorically to context, each document contains an

idiosyncratic system of visual language. The visual intensity of each system depends on the interplay of several levels and coding modes (Kostelnick, 1988, p. 31).

In the light of this, visual literacy emerges as a complex competence that cannot be black-boxed into a simple cognitive function and requires a substantive and procedural understanding of a variety of codes and meaning-making resources to be exercised.

Visual literacy is the ability to understand visual ‘statements’ in diverse mediums and relates to the ability to think, learn, and express oneself in terms of images (Braden & Hortin, 1982) – hence, it implies a set of *pragmatic competencies* (Bianchi, 2003). Such pragmatic competencies relate to the understanding of a subject matter and the contextual meaning that can be attributed to a visual ‘statement’ within its cultural setting, coupled with an analysis of the

Compositional and stylistic principles of the work, [*and the capacity to* evaluate the disciplinary and aesthetic merits of the work, and grasp intuitively the Gestalt, the interactive and synergistic quality of the work (Curtiss, 1987, p. 3).

These pragmatic competencies that relate to the engagement with visualisations and artefacts are difficult to disentangle analytically. That is the reason why they are often regarded as forms of *tacit knowledge* (Polanyi, 2009) that can stabilise and normalise interaction, routines, and procedures (see Latour, 1992; D’Adderio, 2001, 2008). The understanding of how to practically engage with visual conventions is often informed by

Knowledge that is not verbalized, in some cases because it cannot be but in other cases because it may simply be taken for granted or regarded as too trivial to warrant verbalization. The generation or elicitation of all types of tacit knowledge is intrinsically linked to practice (Henderson, 1999, p. 31).

This knowledge that cannot be fully codified has the status of a residual category that encompasses different aspects of non-verbal knowledge and is an instantiation of how “all types of knowledge, however pure, consist in part of tacit rules which may be impossible to formulate in principle” (Collins, 1974). The definitional impossibility that prevents a full formalisation of the competencies implied in the engagement with a visual medium is connected to the aesthetic dimension of such a medium.

The aesthetic dimension of visual artefacts implies that the phenomena of aesthetic communication are implicit in apprehension because of their holistic and polysemic capacity in conveying meaning, and the fact that they are not discursively translatable (Kepes, 2014). In this sense,

Without a physical manifestation, aesthetic qualities would not be perceivable. Without a particular holistic configuration, an image/message would be different in its impact. The qualities of both the parts (details and separate visual elements) and of the whole structure of an image are simultaneously conveyed in a specific gestalt presentation. The aesthetics are embedded in the whole (Dake, 2005, p. 7).

Visual and aesthetic literacy hence suppose the mastery of competencies that are only partially articulated in a verbal and theorised manner. Thus, “visual literacy is not a monolithic universal, but rather culture and experience based. Visual cultures and visual literacies are made of infinite sets of different lexicons” (Henderson, 1995, p. 295). That is because visual literacy is developed based on how a visual culture links material experience to a specific way of seeing the world. While visual literacy is a pragmatic competence of the individual, visual cultures are material world views – ways of seeing that reflect and shape how individuals in a context render the world (Latour, 1986; Alpers, 1983; Baxandall, 1972). In this sense, visual languages and worldviews “develop side by side to the point where language become so ingrained that it constantly supports a specific way of seeing and structuring the world” (Peat, 2002, p. 97).

These elements are intertwined, and aesthetic knowledge can be argued to include a symbolic and experiential component. As Ewenstein & Whyte (2007) argue, symbolically aesthetic knowledge is connected to style, which may be interpreted, in semiological terms, as a vocabulary that enables expression via non-verbal signifiers and signs. Its experiential element, on the other hand, relates to phenomenological aspects connected to feeling, sensitivity, and bodily experiences which affect interaction with a changing material context (Ewenstein & Whyte, 2007). As Stigliani & Ravasi (2018) have shown, the designers' visual and aesthetic literacy also has a declarative component, namely design work supposes the sensitivity to articulate the aesthetic experience that artefacts may deliver. This declarative component is needed to make deliberate choices of design features to achieve an outcome that conveys aesthetic properties that can be recognised by an interactor. Additionally, visual literacy has a procedural dimension, which is what enables designers “to identify the appropriate ‘design language’ for a product under development, and how to translate that language into a concrete ‘design execution’ conveying the intended ‘look and feel’” (Stigliani & Ravasi, 2018, p. 32).

These contributions to the study of visual and aesthetic literacy emphasise the multifaceted nature of aesthetic knowledge and communication (see Strati, 2003; Gagliardi, 2006) focusing on some of the preconditions to engage successfully with the affordances and conventional features of visualisations. Building on these insights, the reflection now turns to visual conventions, which are important manifestations of the codes and products created and adopted by a visual culture.

3.5. Visual conventions and the rhetoric of visualisations

The previous sections established a differentiation among sensory and arbitrary visualisations, highlighting how conventional codes play a fundamental role in communication and interaction. This section investigates the properties of a subset of

the conventional dimension of cultural constraints, namely that of visual conventions (Kostelnick & Hassett, 2003). This is the domain of the *visual language* employed by designers in the realisation of artefacts in specific settings and discourse communities. Each way of visualising information is grounded in conventional practices that are diffused in professional settings and are shaped and sustained by social forces. The visual language of a community is a medium that the designers use to shape, stabilise, invent, and streamline visual information. In this sense, the theorisation of its implications is of paramount importance for designers as

We inhabit a world that relies increasingly on visual language to function, yet the structure of that language remains surprisingly opaque. [...] To function as a language that users can reliably make meaning with, visual language must embody codes that normalize its practices among both designers who deploy it and the [*interactors*] who interpret it (Kostelnick & Hassett, 2003, p. 1).

Such conventional practices are determinants of the ‘goodness of fit’ between an artefact and its situation of use (Simon, 1996). That is because they can constrain design possibilities and expectations regarding usability. Designing, in fact, does not occur in a vacuum:

Design is always the conscious creation of particular artefacts within a longer tradition of practice. It involves a choice of conventions in a context in which there is not just one correct way of doing something (Murray, 2012, p. 25).

The identification of affordances in the interaction with organisational artefacts and the design of interactional possibilities is contingent on factors that relate to the expectations and experiences of communities of practice. In such contexts, a visual language can be understood as the common ground of codes that holds together the visual artefacts in a setting.

It is important to emphasise that conventions are far from being merely rigid structural features that inhibit invention, recombination, and transformation of what is knowable. It is possible to argue that “conventions prompt rather than stifle invention” (Kostelnick & Hassett, 2003, p. 5): Conventions are not invariant features that necessarily undermine the designer’s agency, instead they are aspects that may stimulate adaptation and recombination of visual templates, which can be changed according to emerging circumstances. While, in the short-term, visual-conventional elements can be regarded as constraining factors by designers, they are constantly in flux and ensure a level of familiarity for interactors to engage with the affordances of specific artefacts. The nature and fate of visual conventions rest in the communities of practice that support them, that is because conventions operate in contexts where designers and users control them.

Since designers and interactors can alter, reject or not respond to conventional features, conventions are always dependent on the shared knowledge and practices of specific communities. Additionally, conventions pervade all forms of design (Norman, 1999; Ware, 2012; Henderson, 1998). This is true not only in highly technical fields in which visual and textual conventions play a fundamental role (e.g., in the elements of the construction of a balance sheet) but also in almost every aspect of generic information design (e.g., the use of capital letters in written communication). Combined, these elusive characteristics of visual languages imply that “conventional practice is inherently rhetorical” (Kostelnick & Hassett, 2003, p. 5; see Meyer et al., 2013). Designers create and use artefacts to communicate with interactors and achieve specific ends, in this sense, visual conventions and their rhetorical power

Supply the thread that weaves together our perceptual experiences, creating the underlying structure that makes design a coherent language and prevents it from dissolving into rhetorical anarchy (Kostelnick & Hassett, 2003, p. 11).

Since the transmission of a message and the intended interactional possibilities can only be anticipated and ‘hoped for’ (Arrington & Schweicker, 1992), the rhetorical

relationship between designer and user, in which the designer continuously strives to anticipate how the user will interpret the conventional features of an artefact, is intrinsically uncertain¹⁶.

To ensure an extent of control of direction of such interactional ambiguity, designers deploy conventions based on their interpretation of potential interactors and the context in which they will engage with the artefact in question. Visual conventions are elements that guide the design of artefacts and play an essential role in pre-forming the engagement with such artefacts in practices of future use (Bjørn & Østerlund, 2014). Conventions “organize visual language into functional patterns [...] like the ever-shifting fins of a kaleidoscope” (Kostelnick & Hassett, 2003). These functional patterns, which require acquaintance and repeated exposure to be mastered, have significant implications that relate to the enabling and constraining effects of visualisations.

These characteristics of visual conventions imply their involvement in the creations of artefacts (their design process), in the communication of intended interaction possibilities and content from designers to interactors (the communicative element of engagement with the artefact), and the use the interactors make of the artefacts in practice. Both the affordances (physical and perceived) of the artefacts and their conventional features induce specific modes of engagement with an artefact. The link between these three aspects – design, communication, and interaction – is fuzzy and their black boxing is arbitrary:

Although conventions grease the wheels of communication, those wheels do not turn in self-perpetuating cycles. Only interactions between users in specific situations can sustain conventions, one interaction at the time. Conventions

¹⁶ The inherently opaque relationship between designers and user becomes manifests in the enactment of specific designs. In fact, “context is impossible to predict precisely, let alone control. [...] it is impossible even to fully describe all of the variables involved in the contexts in which one specific convention might be viewed. As a result, we are left with an element of surprise when even a rigid convention is deployed in the most conventional of settings” (Kostelnick & Hassett, 2003, p. 224).

supply a vast reservoir of knowledge about visual language that users bring to a given interaction. [...] Even though each rhetorical situation has unique features, and even though we cannot predict exactly how users will apply conventional knowledge, many situations share similar enough purposes that they prompt designers to use many of the same conventions. Deploying conventions in similar situations both economizes and constrains the [*user's*] interpretation [*and interaction*] (Kostelnick & Hassett, 2003, p. 173).

The quote above illustrates the importance of visual conventions in supporting interaction and communication, while at the same time highlighting their limitations. Conventions can only *pre-form* and *induce* (without determining) ways of engaging with and communicating through visual artefacts¹⁷ (Hutcheon, 2001). To function, they suppose visual literacy both on the part of the designers and that of the users; they are in fact more likely to succeed if both designers and interactors share an understanding of the communicative context. In this sense, visual conventions are not connected to *actual* affordances (i.e., actionable properties) but are an open-ended and uncertain way of supporting the identification of the affordances in question.

For these reasons, as Kent (1993) argues, conventions serve as ‘crutches for meaning-making’. Strictly speaking, they are *not necessary* for communication to happen successfully, but they prop out interactions. That is because the visual conventions that pertain to the domain of information visualisation are *supra-level elements*, namely the "global, top-down visual elements – textual, spatial, and graphic – that orient us

¹⁷ The application of the theoretical coupling of affordances and visual conventions to the study of visualisations presents points of convergence with the notion of mediating instruments, yet it enables the investigation of different concerns. Mediating instruments are performative artefacts that, for example, mediate and frame the interplay between science as practice and markets (Miller & O’Leary, 2007; Pollock & D’Adderio, 2012). Their role is defined regarding the formal and agentic links between separated areas that these tools establish and sustain (Miller & O’Leary, 2007). The practice of mediating instruments results in transformations aimed at establishing coordination in a field (Burchell et al., 1985; Miller & O’Leary, 2007). Although mediating instruments can be ‘designed’ to elicit reflexive attitudes towards the dialectics between matters of fact and matters of concern (Revellino & Mouristen, 2015), their role is appraised about a field of practice, which is supra-individual. This is not in opposition to affordances. Affordances have a narrower scope about how they pre-form individual interactions. Their explanatory power informs each interaction and only by aggregation the mechanics of a field of practice (Stark & Paravel, 2008). Hence, affordances and mediating instruments are conceptually compatible but have a different scope, and the former enables more thorough understanding of individual-level engagement between an interactor and an artefact. Because of this specificity, affordances are a more promising and precise lens to explore the design properties of visualisations.

perceptually and rhetorically when we encounter a [*visual artefact*]" (Kostelnick, 1996, p. 9). This is evident, for instance, in one of the most consequential sites to explore visual conventions in action, namely studying the layout of documents (see Barton & Barton, 1993):

Layout does not name or depict; it does however ‘dispose’, organize and indicate aspects of the social/ontological ‘status’ of representations, as ‘known’ and ‘given’ or as ‘new’ or ‘unknown’. In doing that, *layout* ‘orients’ viewers/interactants socially, as ‘part of my group or not’; epistemologically, as ‘knowing or not’; and ontologically, indicating the ‘social status of knowledge’ (Kress, 2009, p. 92).

The perceptual and rhetorical guidance operated by visual conventions creates a degree of familiarity in engaging with different artefacts designed for the same or similar user groups in a setting. In this sense, visual conventions and their reoccurring design features are influential in orchestrating distributed cognition (Stigliani & Ravasi, 2012). Accordingly, layout features such as

Formats and genres are externalized cognitive schemas, strategies for making us smarter by standardizing complex repeated experiences into recognizable patterns. They are part of the *distributed cognition* by which culture is propagated and shared (Murray, 2012, p. 17).

That is not to say that poorly designed conventions cannot be detrimental or even dangerous. It is possible to argue that poorly designed organisational artefacts and strategy tools can compromise learning processes (Tufte, 2006), as well as organising and coordination (see Jarzabkowski & Kaplan, 2015). That is because of how they may induce quick classification of emergent and potentially unexpected phenomena as ‘in family’, thereby creating gaps and dangerous blind spots in understanding and interpretation (Weick & Sutcliffe, 2015). Accordingly,

Although the grip of conventions can greatly benefit the users by creating a stable environment for shaping and interpreting visual language, conventions can also become so entrenched that they interfere with meaning making by not changing to match changed conditions or by leading to mindless, unwarranted conformity (Kostelnick & Hassett, 2003, p. 182).

This section discussed the importance of a specific subset of the category of cultural constraints, namely that of visual conventions. Visual conventions, as the features of the visual language deployed by designers in the creation of an organisational artefact, perform a fundamental role in supporting (or hindering) engagement with organisational artefacts. The next section positions theoretically the design framework by linking the issues tackled so far with the idea of sociomateriality.

3.6. Affordances and visual conventions: Positioning and implications

The theoretical coupling of affordances, visual conventions, and literacy has implications in relation to the epistemological and ontological status of visual artefacts. This section explores the issue of how visual artefacts influence interaction by linking it with the notion of sociomateriality. In so doing, this section also illustrates the ontological and epistemological position that informs this study; for this reason, the following considerations also inform the methodological choices that are discussed in the next chapter. In this section, I argue that the affordances of visual artefacts and the visual conventions deployed in their design are promising lenses to “theorize the simultaneous existence of pattern and contingency” (Winsor, 1999, p. 200) about how visual artefacts pre-form interaction. The focus of this section is on how the outcomes of interaction with a visualisation

Depend on what people do, on how they enact the design, and such doing is never determined by the design, for in the liminal space of enactment there lies the opportunity for slippage, for resistance, for learning, for change (Orlikowski, 2004, p. 94).

Hence, the focus is on how interactors can “choose to do otherwise” (Giddens, 1984, p. 4; see D’Adderio, 2008; Leonardi, 2011) with the artefacts and technologies they are enacting. At the same time, this position stresses that the material and design configuration of such artefacts are attributes that ‘plainly matter’ (Hatherly et al., 2008) in influencing the outcome of each interaction¹⁸. In this sense:

The influence a technology has upon human agency is not reflected in the (non)exhaustive use people may make of the possibilities it offers. It is rather captured by the distinctive ways by which a technology invites people to frame a delimited domain of tasks or activities and organize their execution (Kallinikos, 2002, pp. 289-290).

Visualisations can pre-form interaction and create particular forms of visibility on organisational matters by means of their design (Latour, 1986; Henderson, 1999), which is their deliberately achieved material configuration. In creating visualisations, designers produce social and material realities and visibilities by “describing, inscribing, prescribing and proscribing how, why, when and where” (Orlikowski, 2004, p. 92) interactors will subsequently engage with their products. This activity of pre-forming future interaction is problematic, as

Each standard and each category [*deployed or invented by the designer*] valorizes some point of view and silences another. This is not inherently a bad thing – indeed it is inescapable. But it is an ethical choice, and as such it is dangerous – not bad, but dangerous (Bowker & Star, 1999, pp. 5-6).

Since designs are representations of possible realities, their ultimate value is dependent on the engagement of interactors, and their pre-forming of such engagement is both greatly important and under-researched.

¹⁸ From this perspective, “the inherent flexibility and adaptability of human practices implies that rules may attempt to guide behaviour [...] but human actors can always operate discretion in interpreting the rule or procedure, assign meanings [...] and ultimately decide whether, how and when to abide by, work around, or altogether reject them” (D’Adderio, 2008, p. 773).

Visualisations – through their design and practice – can become the common ground for collectively negotiated ideas and assemblies of action. As Henderson (1991, 1995, 1998) has shown, visualisations may function as *conscription devices*¹⁹, that constrain engagement as

Anyone who wants to participate in the design process must do so by interacting with them. Because they represent a design group's negotiated ideas, and hence its distributed cognition, they also structure how work gets done in groups (Henderson, 1998, p. 140).

In the light of that, the form of visualisations influences interaction as well as the culture of the organisation in question. *Visualisations*, in connection to the broader *visual practices* and *visual ethos* in a setting (Kostelnick, 1988, 1996), are involved in "defining both what it is to see and what there is to see" (Latour, 1986, pp. 9-10). In this sense, how interactors in a culture see the world is mutually influenced by how they render this world.

This culturally-mediated pre-forming function of visualisations is connected to the perception of their affordances (Norman, 2013), which constitutes the domain of how the artefact can be used. Visual conventions, as the instantiations of the visual language and culture that characterises an organisation, are the visual-rhetorical features that orient the interactor and enable affordances to emerge through repeated practice. The interplay of affordances and conventions generates non-deterministic processes of

¹⁹ Henderson (1991, 1995, 1998) theorised the notion of *conscription device* building on the concept of boundary objects proposed by Star & Griesemer (1989). Star (1989, p. 46) describes boundary objects as "objects which are both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites." Conscription devices are theorised as "a subgroup of inscription devices, that enlist group participation and are receptacles of knowledge that is created and adjusted through group interaction with a common goal" (Henderson, 1999, p. 54). In this sense, working as obligatory points of passage (D'Adderio, 2001), conscription devices play important roles in stabilising and normalising interaction by relying on the standardising effects of the 'power of default' in approaching organisational activities (D'Adderio, 2008; Ferguson, 1999).

constrained opportunities (Stark & Paravel, 2008). Designers can exploit these opportunities in their uncertain attempt to convey the intended interaction possibilities to their products (Stigliani & Ravasi, 2018). However, pre-forming is not univocal determination (Hutchby, 2001), as ultimately the “realm of action consists of people choosing to use a technology in a certain way” (Leonardi, 2013, p. 64). The explanatory power of these concepts is connected to how they enable to theorise on the imbricated interplay of the social and the material in the study of artefacts. It is possible to argue that affordances and visual conventions can offer a viable mediation between the opposing poles of realism and constructivism. According to Hutchby (2001, p. 444):

Affordances are functional and relational aspects which frame, while not determining, the possibilities for agentic relation to an object. In this way, technologies can be understood as artefacts which may be both shaped by and shaping of the practices humans use in interaction with, around and through them. This ‘third way’ between the (constructivist) emphasis on the shaping power of human agency and the (realist) emphasis of the constraining power of technical capacities opens the way for new analyses of how technological artefacts become important elements in the patterns of ordinary human conduct.

From this perspective, the activity of ‘framing without determining’ that designers perform in the realisation of their products is grounded on a theorisation of the social and the material that is theorised as co-constitutive. This theorisation hence regards artefacts “as objective reality and as socially constructed product” (Orlikowski, 1992, p. 423).

This perspective, which considers the ontological entanglement of the social and the material, has a focus which

Does not privilege either humans or technology (in one-way interactions), nor does it link through a form of mutual reciprocation (in two-way interactions).

Instead, the social and the material are considered to be inextricably related (Orlikowski, 2007, p. 1437).

This epistemological position is of central importance for the study of visualisations, since “any design is an instantiation of theories about material influences on behaviour, whether explicit or implicit” (Gaver, 1996, p. 112). On the one hand, this position stresses the importance of physical-visual-material features of an artefact in supporting interaction. On the other hand, it recognises how social and conventional forces, as well as the idiosyncratic domain of interpretation, are fundamental in the design and practice of artefacts.

The interpretative dimension is here understood as a property of the *interface* between artefact and interactor, which is guided but not exhausted by materiality. Hence, this position avoids a central problem of hermeneutic approaches:

The hermeneutic vision is correct in stressing the multiplicity of relevant interpretations of situations, users and artifacts, but too easily conflates multiplicity and infinity, settling for indeterminate subjectivity (Carroll & Kellogg, 1989, p. 13).

The emphasis on the enabling but also constraining properties of artefacts recognises the interpretively flexible nature of technology (Orlikowski, 1992, 2010). By interpretively flexible, Orlikowski (1992, p. 405) means “the interaction of technology and organisations is a function of the different actors and socio-historical contexts implicated in its development and use”. This position, which assumes that technology as such is already to an extent institutionalised, avoids dualistic separations between design and use. Instead, it stresses how

Interpretive flexibility is an attribute of the relationship between humans and technology and hence it is influenced by characteristics of the material artefact

[...], characteristics of the human agents [...], and characteristics of the context (Orlikowski, 1992, p. 409).

Hence, the theorisation of the role of affordances and visual conventions within the framework of sociomateriality bypasses the problem of the *epistemic form* of technology, which is left largely unaddressed by the research tradition that subscribes to the ‘social shaping’ approach²⁰. To avoid these issues, relying on sociomateriality offers two advantages. On the one hand, it avoids an approach based on what Grint & Woolgar (1997) define as ‘technicism’, namely the belief that technology has objective ‘effects’ that can be quantified and predicted, and are largely independent of the roles that actors play in the interaction with technologies. On the other hand, this approach enables to move beyond the opposing ideas of ‘*essentially technical*’ or ‘*interpretive textual*’ properties of artefacts (Hutchby, 2001).

In so doing, it overcomes specific issues that characterise the ‘*anti-essentialist*’ tradition of argumentation in STS. The anti-essentialist perspective is problematic because it does not account for constraints in possible interpretations and meaning attributions in the engagement with artefacts (Hutchby, 2001). If technology is interpreted from that perspective, one would have to rely on an interpretation of artefacts as intrinsically empty and capable of bearing any given interpretation. Considering technologies as ‘open forms’ implies regarding artefacts as *tabulae rasa*. The anti-essentialist perspective does not account adequately for the shaping power of the object. In this sense, it would not lead to successful designs because it does not afford the establishment of invariant relations between the artefact and the interactor. Contrariwise, focusing on affordances is a way “to accept the realist position that there are features of artefacts that are not constructed through, or retrievable only by means of, accounts” (Hutchby, 2001, p. 450). Thus, the notion of affordance allows

²⁰ The social shaping approach to technology is a “generic label for those accounts which suggest that the capacity of technology is equivalent to the political circumstances of its production” (Grint & Woolgar, 1997, p. 19), and, broadly speaking, encompasses the traditions of sociology of scientific knowledge (e.g., Latour & Woolgar, 1986) and the social construction and shaping of technology approach. These approaches claim to be wanting to ‘open the black box of technology’ but tend to put too much emphasis on explanations of the content and context of technology.

compatibility between the agency and the politics of the artefact (Latour, 2005; Winner, 1980), its interpretive flexibility and the capacity of interactors to choose to do otherwise when engaging with a technology (Orlikowski, 1992, 2007).

In light of these considerations, a sociomateriality perspective offers an ontological framing that affords a comprehensive exploration of the interactions among actors, artefacts, technologies, and activities in organisational settings (Leonardi et al., 2012; Jones, 2013). Since organisational practices shape the materiality of technologies and artefacts that, in turn, shape the practices themselves, technologies and artefacts cannot be studied without reference to their practice. This approach is not at odds with the exploration of the design of visual artefacts relying on theoretical notions borrowed from design theory. In fact, while design research is characterised by a practical interest in building useful interfaces, sociomateriality is an ontological approach. On the one hand, sociomateriality is grounded on a relational ontology that enables to tackle the imbricated (Leonardi, 2011) nature of artefacts, interactors, and practices. In this sense, it “offers an analytical perspective from which neither artefacts, nor people, nor practices are seen naked and alone, revealing solely their inherent properties” (Bjørn & Østerlund, 2014, p. 8). On the other hand, design research is open to contributions from other disciplines (Love, 2000) if they can offer insight into how the design and practice of artefacts can operate synergistically. In this sense, sociomateriality and design not only are compatible but can be reciprocally informative.

A framework concerned with sociomateriality and design, such as the one proposed in this thesis, is however characterised by an inner tension. It is, in fact, stimulated by a theoretical interest in unpacking the complexity of sociomaterial practices while seeking to reduce the complexity of practice to enable the design of artefacts. This tension is alive throughout the thesis and informs both the empirical exploration of how reporting designers construct visualisations in Crossrail, as well as the theorisation of the design principles in the discussion chapter.

3.7. Concluding remarks

This chapter sought to articulate a comprehensive framework to explore the design and practice of visual artefacts in complex settings. It started by discussing the importance of Simon's *The Sciences of the Artificial* as the cornerstone for a design theory that is relevant to the research domain of management and accounting studies. Building on and moving beyond Simon (1996), the chapter then turned to an overview of different approaches that emphasise the importance of designing without final goals to tackle issues connected with complexity and emergence. To tackle the design of artefacts that aim to support and facilitate engagement with organisational settings characterised by those features, the study then presented an articulation of the notions of affordances, visual and aesthetic literacy, and visual conventions.

The discussion of affordances unpacked how interactional possibilities frame without determining the outcome of the engagement with visual and material artefacts. Visual and aesthetic literacy showed that the design and practice of artefacts suppose certain pragmatic competencies that are difficult to disentangle from an analytical perspective but are crucial in fostering (or hindering) interaction. The discussion of the properties of visual conventions illustrated the open-ended and ambiguous way in which conventional elements pre-form understanding and interpretation. Combined, these considerations emphasised both the power of the material configuration of artefacts in shaping interaction as well as the centrality of how such artefacts are enacted in practice. These concerns were further unpacked in the final section of the theory chapter, which articulated the ontological and epistemological positioning of this study. Additionally, by detailing the relationship between sociomateriality and design, the chapter further specified the explanatory power and limitations of the theoretical lenses that will guide the discussion of the empirical findings.

4. METHODOLOGY

Since there is no such thing as an innocent reading, we must say what reading we are guilty of (Althusser, 1970, p. 14)

Building on the ontological and epistemological considerations discussed in section 3.6, this chapter discusses how the study was carried out by explaining the methodological choices that inform this project and justifying their appropriateness to address the research questions. The chapter is structured as follows. Section 4.1. critically discusses the choice of qualitative case study research as a viable method to explore the research questions (section 1.1). This section focuses on the suitability of case studies to explore how visualisations are designed and practised and discusses the epistemological status of qualitative case studies. Drawing from Agamben's (2009) notion of 'paradigmatic case', this chapter investigates how cases can grant stable ground for social scientific enquiry by overcoming the issue of context-specific knowledge as opposed to rule-governed, generalizable knowledge. Section 4.2 illustrates why megaprojects are ideal sites for the concerns of this research and offers a description of the Crossrail programme. Additionally, it explains why visual practices in the megaproject organisation constitute a paradigmatic case of the phenomena being investigated. Sections 4.3 discusses the approach towards data collection and fieldwork, explaining how the selection of data collection methods is consistent with the study's approach. Section 4.4 discusses how the data was analysed.

4.1. Qualitative case study research

The development of a qualitative case study was selected as a viable method to explore the research concerns of this project since it enables nuanced exploration of the design and practice of visualisations in organisational contexts. Although research based on case studies is popular in business studies and the social sciences, it is worth exploring

epistemological issues that relate to the knowledge that can be derived from this approach to demonstrate its validity in the exploration of the concerns of this study.

Czarniawska (2014, p. 21) defines a case study as “*the study of the occurrence of a phenomenon – a chain of events, usually limited in time, usually studied retrospectively*”. However, it is important to contextualise the definition of a case study with its status as a scientific method. It may be possible to disregard case studies because of their potentially anecdotal value. Positivist accounting scholars (e.g., Zimmermann, 2001), often assume that case studies can be employed to ‘find out things’ that happened before producing statements of causality that can be explored relying on quantitative methods. This perspective is misleading as, in its pursuit to identifying results that are governed by analytical rationality, assumes the possibility of developing a genuinely predictive – and hence falsifiable (Popper, 1959) – theory in the social sciences domain.

Another criticism towards to case study methodology relates to the status of the knowledge obtainable from this type of research, which is context-specific instead of context-independent. According to this critique, if the knowledge acquired relying on cases is valid only within the context of the setting where the phenomenon is studied, its implications are of limited relevance to the body of scientific knowledge. However, it is worth considering that

Social science has not succeeded in producing general, context-independent theory and, thus, has in the final instance nothing else to offer than concrete, context-dependent knowledge. [...] Proof is hard to come by in social science because of the absence of ‘hard’ theory, whereas learning is certainly possible (Flyvbjerg, 2006, pp. 223-224).

Accordingly, the context-dependent nature of the case study approach should not be misinterpreted as an attribute that goes against its validity as a method of social-scientific enquiry (Cooper & Morgan, 2008; Czarniawska, 2014). If it is true that

predictive theories cannot be identified in the social sciences, then achieving context-specific knowledge is not only a necessity, but it is also inherently valuable (see Ragin, 1992). As Cooper & Morgan (2008, p. 164) argue:

Research based on a few carefully selected observations has an advantage for understanding and communicating such detailed aspects of business activities compared with studies using large samples and the relative few variables that can be observed for the whole sample.

Carefully selected case studies can produce “the type of context-dependent knowledge that research on learning shows to be necessary to allow people to develop from rule-based beginners to virtuoso experts” (Flyvbjerg, 2006, p. 221). The transition from rule-based learning to expert judgement incorporates tacit and elusive elements (Polanyi, 2009) that escape the strict definition of generalizable knowledge. In fact, as Kuhn (1970) has shown, formal generalisation is often overrated as the source of scientific knowledge progression.

The fact that cases do not offer knowledge that, as such, is generalizable does not undermine their validity in producing knowledge by accumulation. In this sense, ‘gaining knowledge’ by accumulation can be achieved if cases are designed with an effort of them being instrumental and not merely intrinsic (Stake, 1995). An intrinsic case study is one that contributes to learning about its particular object of inquiry, whereas an instrumental case is one that intends to “contribute to learning about phenomena about which the object of inquiry is an instance” (Barzelay, 2007, p. 524). Contrary to what Barzelay (2007) argues, it is also essential to locate the validity of cases in relation to the productive tension that exists in between intrinsic and generalizable knowledge. In fact, it is possible to argue that

One can often generalize on the basis of a single case, and the case study may be central to scientific development via generalization as supplement or alternative to other methods. But formal generalization is overvalued as a

source of scientific development, whereas ‘the force of example’ is underestimated (Flyvbjerg, 2006, p. 228).

Flyvbjerg’s quote makes two essential points. Firstly, generalisation is to be understood as only one of the many instruments for understanding, and not its teleological goal. Secondly, ‘the force of the example’ is connected to paradigmatic validity case studies can acquire if they present extreme and critical features (Kuhn, 1970). Paradigmatic cases are instrumental in learning due to the logic of their operation, which is the topic of the next section.

4.1.1. The epistemological status of case studies

Drawing from Agamben’s (2009) notion of ‘paradigmatic case’, this section explores the status of knowledge acquired through qualitative case studies and links these concerns with issues of case selection. The objective is to justify the validity of case studies as a method in the social sciences, trying to overcome the two positions that argue for the anecdotal value of case study accounts or confine social scientific knowledge to a context-specific horizon.

According to Agamben, who draws from and builds on Kuhn, “a paradigm is simply an example, a single case that by its repeatability acquires the capacity to model tacitly the behavior and research practices of scientists” (Agamben, 2009, p. 11; see Kuhn, 1970, p. 187). Kuhn (1970) theorised the notion of paradigm in two different ways: (1) A disciplinary matrix that refers to the common vision of the world, techniques, models, and values to which members of a specific scientific community more or less knowingly subscribe to; (2) A common example that substitutes substantive rules and affords the articulation of a coherent and specific tradition of enquiry. Kuhn (1970) highlights that sciences in the ‘normal phase’ are held together by paradigms that govern the normal science in the absence of rules. Accordingly, a paradigm is not a rule or a canon of scientificity, but an individual instance characterised by the singular

logic of the example. In other words, paradigmatic cases – such as Foucault’s Panopticon or Freud’s ‘Wolf-Man’ – can be interpreted as a “singular object that, standing equally for others of the same class, defines the intelligibility of the group of which it is part and which, at the same time, it constitutes” (Agamben, 2009, p. 17). In this sense, paradigmatic cases are epistemological figures that can create a broader problematic context that they constitute by conserving the inner dynamics of the elements without crystallising them in a static and essentialist configuration.

However, it is important not to confuse the epistemological functioning of paradigmatic cases with the metaphorical transfer of meaning (see Arrington & Schweicker, 1992). As Agamben (2009, p. 18) shows, a paradigm is “a singular case that is isolated from its context only insofar as, by exhibiting its singularity, it makes intelligible a new ensemble, whose homogeneity itself constitutes”. In other words, the validity of a paradigmatic case implies that a given term is deactivated from its normal use, not to be transferred metaphorically to another context or domain (Walters, 2004), but to present a canon that cannot be shown in any other way. Almost paradoxically, a paradigm produces knowledge only insofar as it is irreducible to universals, namely thanks to its context-dependent nature.

The epistemological validity of a case and its basis for generating a type of knowledge that exceeds the domain of the context-specific lies in the suspension of the particular-general pair as the archetype of inferential reasoning. The paradigmatic case establishes a rule that is not independent of its example. In other words, “the paradigmatic group is never presupposed by the paradigms; rather, it is immanent in them” (Agamben, 2009, p. 31). In this sense, paradigmatic cases show that detailed and context-dependent knowledge can be much more than anecdotal evidence. These considerations are clarified by the etymology of the word ‘paradigm’. It derives from the Greek word *para-deiknymi* as something that ‘shows beside itself’, as a form of intelligibility that does not precede the phenomenon but stands ‘beside’ it analogically, grounding both its intelligibility and of the class it constitutes (Agamben, 2009).

Relying on Agamben's (2009) notion of paradigmatic case, it is possible to shed new light on how case studies can overcome the issue of context-specific knowledge as opposed to rule-governed, generalizable knowledge. Drawing from Kuhn's (1970) dual meaning of paradigm, Agamben (2009, p. 31) shows that "a paradigm is a form of knowledge that is neither inductive nor deductive but analogical. It moves from singularity to singularity". In so doing, a paradigmatic case overcomes the dichotomy between context-specific and general by replacing it with an analogical model. This, in turn, implies that "the paradigmatic case becomes such by suspending and, at the same time, exposing its belonging to the group, so that it is never possible to separate its exemplarity from its singularity" (Agamben, 2009, p. 31). Agamben's reflection on the functioning of 'paradigmatic cases', and its application to epistemological issues of qualitative case study methodology attempted in this section of the study, aims to clarify their analogical functioning.

Analogy covers a vast conceptual field that sparked controversy in the social sciences. From a practical standpoint, analogy – as a form of argument that moves from one particular to another particular, or from singularity to singularity – is often considered unproblematic and fundamental in the identification of 'something' and in the distinguishing of 'something' from 'something else', as well as in the perception of the continuity of the self who lives the experiencing process (see Clark, 1993, 2008). However, moving from practice to theory, analogical reasoning acquires an ambiguous status which is often regarded as a liminal space between logical inference and experience-driven and content-based reasoning – in this sense, it cannot be assimilated to either the domain of logic or psychology. Agamben's (2009) reflection and its application to case study methodology enable to distinguish the qualitative status of analogy and its epistemological validity while highlighting its irreducibility to inference.

Analogical knowledge based on case studies shares commonalities with the workings of Blumenberg's (2010) 'absolute metaphors', namely metaphors that leap into a void that concepts are unable to fill and are not based on the aforementioned idea of metaphorical transfer. The power of such metaphors lies on the fact that their irreducibility to a formal language cannot be brushed aside, as they are not posed or invented by the knowing subject, but we find them already posed in the ground of our existence. Agamben (2009) shows that, against the triumph of logic and the marginalisation of the analogy that characterises Western thought and research methodology, it is not necessary to overthrow the relationship between the two, but rather to look beyond the division and explore how one can learn from the similar without resorting to generalisation. Paradigmatic cases, working by analogy, acquire a specific position and knowledge status. These considerations, by illustrating the dynamics of the idea of paradigmatic cases, offer a new take to the issue on how it is possible to learn from case studies (see Flyvbjerg, 2006; Quattrone, 2006; Barzelay, 2007; Cooper & Morgan, 2008), emphasising the importance of navigating the liminal space between context-dependent knowledge and universals.

An important implication of these considerations about case study methodology is the issue of case selection and the search for cases and sites that present paradigmatic features. As Cooper & Morgan (2008, p. 160) argue, it is advisable to select "phenomena in which the context is crucial because the context affects the phenomena being studied (and where the phenomena may also interact with and influence its context)". This needs to be coupled with the identification of what a given phenomenon is a case of (Czarniawska, 2014), avoiding the confusion between site and research phenomenon. Avoiding this confusion is not trivial, as the conceptualisation of the research phenomenon can be broader (or narrower) than an individual organisation. Additionally, there are essential pragmatic concerns that relate to the practicalities of conducting qualitative case studies. One of such issues is that case research needs to be both theoretically informed while, at the same time, preventing that data collection is driven by a desire to backing the researcher's preferred theory (Eisenhardt, 1989). This issue is known as verification bias or the often-unintentional risk that the research outcomes may lead to the confirmation of

pre-existing assumption a researcher holds about a phenomenon. While this bias is a priori unavoidable since data are recognised as such through the lens of a disciplinary background, it appears to be particularly problematic about qualitative case study research (Diamond, 1996).

Some argue that a crucial problem in this regard is that Latin word *data* – meaning ‘things given’ – conveys a misleading sense of objectivity, whereas researchers should deal in *capta*, meaning ‘things seized’. The word *capta* is more representative of qualitative case study methodology, as its outcomes are situated, partial, and constitutive²¹ and often relate to what Barzelay (2007) calls ‘second-hand experience’, or vicarious experience that is ingenuously seized by a researcher that only has access to accounts of experiences, which are edited even before being told, let alone reported. However, qualitative case studies offer the opportunity for the researchers to immerse themselves in a given setting to explore how a phenomenon unfolds. In this sense, the empirical setting can often ‘speak back’ (Geertz, 1995), which in turn implies that the researcher has to reconsider their assumptions and expectation about the empirical site throughout their study (Ahrens & Chapman, 2006).

These issues are deeply connected to the development of reflexivity in case study research. Reflexivity requires an acknowledgement of the ideological, cultural, and historical power dominant forms of inquiry exert over the researcher and the phenomenon (Alvesson, 2010). Methodological issues regarding how the researcher's biography is involved in the production of knowledge relate to issues of objectivity and subjectivity, social reality, and identity. Even though there is an emerging consensus that interpretation as such cannot be controlled, this does not imply that certain individual positions and readings are not more privileged than others in the interpretation of research data (see Woolgar, 1988; Grint & Woolgar, 1997). Since, as

²¹ As Drucker (2011, p. 5) argues: “Capta is not an expression of idiosyncrasy, emotion, or individual quirks, but a systematic expression of information understood as constructed, as phenomena perceived according to principles of interpretation. [...] By qualifying any metric as a factor of some condition, the character of the ‘information’ shifts from self-evident ‘fact’ to constructed interpretation motivated by a human agenda.”

Dunne (1996, p. 143) argues, “the self lacks the substantiality and discreteness of an object which is amenable to direct description or explanation”, issues around subjectivity – ‘subjective’ is here used as shorthand for interpretive construction – are challenging to mediate and interpret. In the interpretivist study of non-discrete organisational phenomena, it is fundamental to develop strategies to mitigate the propensity of imposing a specific vocabulary and order onto the phenomena observed (Alvesson, 2010). Even though this is to a significant extent unavoidable, focusing on preventing to normalise and classify as ‘in-family’ uncertainty, fluidity, and tensions can help systematically keep into account different viewpoints that can prevent the development of a one-dimensional construction of the research work (Quattrone, 2006; Alvesson, 2010).

4.2. Case selection and background

The objective of this section is to discuss the rationale behind the selection of the case setting of this thesis. The case study focuses on the visual practices connected to the reporting function in the Crossrail megaproject. The organisation of infrastructure programmes offers a good setting where to explore pertinent organisational challenges (Boland et al., 2008; Revellino & Mouritsen, 2015; Quattrone, 2017; Themsen & Skaerbaek, 2018), and for this reason “the physical nature of the built environment that is generated, and the material [...] artefacts that are used in its production, have attracted scholars to investigate the role of sociomaterial practices in this context” (Whyte, 2013, p. 45). The Crossrail site was selected because it constitutes what has previously been defined as a paradigmatic example of the challenges surrounding the design and practice of visualisations in complex and dynamic settings.

Infrastructural megaprojects – of which Crossrail is a notable instance regarding size, ambition, and delivery performance (NAO, 2014) – are particularly complex organisational settings characterised by dynamism, instability, a multitude of interfaces, stakeholders and sponsors as well as non-standard technologies (see Flyvbjerg, 2007, 2014). Because of these reasons, they are paradigmatically complex

settings to manage, and their organisation requires the aggregation of vast amounts of performance and delivery information for a multitude of stakeholders. Additionally, infrastructure megaprojects are characterised by particularly developed visual tools for design, planning, and delivery that are instantiations of visual cultures associated with the engineering, project management, and accounting profession (see Ferguson, 1999; Henderson, 1999; Whyte, 2013). Accordingly, the selection of the site (i.e., Crossrail) and the case (i.e., the visual practices in Crossrail) were guided by the concerns discussed above about the notions of paradigm. In this sense, the study explores how visual and material artefacts that are the product of sophisticated visual cultures supports and shapes the engagement with a paradigmatically complex setting. The next section discusses the general features and management challenges of megaproject delivery and offers a description of the Crossrail programme.

4.2.1. Megaprojects as sites of economic, social, and technical significance

According to Hirschman (1995), infrastructural megaprojects are settings of great socio-political, technical, and economic interest as they are potentially ‘trait making’ in their capacity to profoundly alter the structures of societies and their development processes. Megaprojects can be defined as:

Large-scale, complex ventures that typically cost US\$1billion or more, take many years to develop and build, involve multiple public and private stakeholders, are transformational, and impact millions of people. [...] They are not just magnified versions of smaller projects. Megaprojects are a completely different breed of projects in terms of their level of aspiration, lead times, complexity, and stakeholder involvement. Consequently, they are also a very different type of project to manage (Flyvbjerg, 2014, p. 6).

Not only are megaprojects large and challenging to manage, but they are a continually growing organisational and policy delivery phenomenon that serve multiple objectives that often go beyond their technical realisation (e.g., economic growth, job creation, and political agendas). Beyond the general societal and sociological trend of the

projectification of society (Jensen et al., 2016), the scale of spending in megaprojects has only accelerated pace, to the point that *The Economist* (2008) called the increasing investment in megaprojects “the biggest investment boom in history”. The domain of megaprojects is not confined to infrastructure, as they are employed as the preferred delivery model for services, goods, and policy across an always expanding range of business and public sectors, which include but are not limited to: Information Technology, government administration systems, intelligence, defence, major events, Big Science programmes, industrial plants, space exploration, mining, water and energy, and so forth. If we are to comprise under the label of ‘megaprojects’ ambitious ventures in the sectors above, then a conservative estimate of the total global spending on megaprojects covers approximately 8% of global GDP, with spending estimated in the range between US\$6-9 trillion per annum (Flyvbjerg, 2014).

Part of the drive behind this investment boom can be identified in the Promethean ambition that characterises these ventures, which are primarily attractive to decision-makers given their ‘sublime’ attributes (see Miller, 1965; Marx, 1967; Frick, 2008). One of such ‘sublimes’ is the technological one, namely the excitement and drive that scientists and engineers get from designing and realising innovative projects that redefine what is technically possible at any point in time (Frick, 2008). The ‘political sublime’ is connected to the drive politicians gain from building ‘monuments’ to themselves, their achievements, and their parties, which may be connected to legacy and their possibility of making history (Flyvbjerg, 2012, 2014). The ‘economic sublime’ relates to the vast budget of megaprojects that can benefit stakeholders such as businesses, trade unions, contractors, consultants, investors, developers, and landowners (Flyvbjerg, 2012). Lastly, the ‘aesthetic sublime’ relates to how architectural and infrastructural megaprojects can alter the landscape, creating unique landmarks that may become universally recognised symbols of cities and even nations.

These considerations illustrate some of the potential benefits that the realisation of the right project in the right manner might have. However, given the magnitude and risks

involved in the delivery of such programmes, the potential for mistakes and errors is possibly catastrophic. According to Flyvbjerg (2007), major infrastructure programmes are risky because of long planning horizons and complex interfaces, which may influence and change the scope and ambition level of the programme over time. Additionally, as temporary project structures, megaprojects are characterised by an always-unfolding ontology that causes the occurrence of unexpected emerging properties (Nocker, 2006; Molloy & Wittigton, 2006) which complicates the topology of unexpected events and their prediction (Priemus, 2010; Piperca & Floricel, 2012). These issues are not exclusively rooted in the characteristics of the settings, but also on the people involved and their behavioural limitations (Williams & Samset, 2010; Priemus, 2010). In this sense, megaprojects are particularly exposed to what Taleb (2010) calls ‘black swan’ events, namely extreme unexpected events that are made even more problematic by managers’ ‘tunnel vision’, optimism bias and the retrospective orientation through which expectations-defying events tend to be rationalised (see Kahneman, 2011; Weick & Sutcliffe, 2015).

Additionally, in megaprojects technology is often not standard and budget contingencies tend to be inaccurate and vague (Giezen, 2012). These non-standard features may lead to what Budzier & Flyvbjerg (2013) call ‘uniqueness bias,’ namely the unconscious tendency of managers and planners to regard their programme as more unique than it is. The misattribution of uniqueness may hinder learning processes, as it fosters the belief that lessons learned from other programmes do not apply to their setting. Given their size and the amount of public and private stakeholders involved, megaprojects are ‘pluralistic settings’ defined by “diffuse power, ambiguous goals and multiple actors with diverse values and interests” (Denis et al., 2006, p. 350), which make them particularly challenging to manage because of the difficulty to impose top-down decisions.

Taken together, these characteristics of megaproject management result in mediocre performance regarding benefits realisation and widespread misinformation about

costs, benefits, and risk (Flyvbjerg et al., 2005). For these reasons, 91% of large-infrastructure programs incur significant cost overruns (Flyvbjerg, 2007) and there are cases with a calamitous history such as the Suez Canal (1,900% cost overrun), Scottish Parliament Building (1,600% cost overrun), Sydney Opera House (1,400% cost overrun) – see Flyvbjerg (2014, p. 10). Table 1 below summarises the poor track record regarding cost overruns and benefits realisations that characterises the delivery of megaprojects worldwide (updated 2015).

	Roads	Bridges/Tunnels	Energy	Rail	Dams	IT	Olympics
Cost overrun	25%	32%	36%	42%	90%	107%	156%
Frequency of cost overrun	8/10	7/10	6/10	8/10	7/10	5/10	10/10
Schedule overrun	39%	22%	38%	42%	44%	39%	0%
Benefits shortfall	7%	-7%	n/a	-51%	-11%	-24%	n/a
Cost Black Swans	8%	11%	7%	5%	10%	18%	5%
Duration (years)	5.6	8.0	5.3	8.2	8.2	3.3	7.0

Sources: Ansar et al. (2016); Budzier & Flyvbjerg (2013); Flyvbjerg et al. (2016).

Table 1. The poor performance track record of megaproject delivery

A recent report commissioned by the UK Cabinet identified in issues of accounting, governance, and approach to the management of risk fundamental challenges that lie at the core of the underwhelming delivery performance of megaprojects (IPA, 2017a, b). The commonly expressed source of failures is the management related to the support of decisions, precisely at the early project stages (i.e., design, planning, bidding, and procurement). The institutional pressures of delivering faster and more ‘publicly transparent’ decisions pose the risk of a shift of responsibility towards

automated systems, potentially compromising decision-making processes and making them riskier if the assumptions behind optimisation models remain poorly understood (Bovens & Zouridis, 2002). It appears that the “the project management discipline has so deeply committed itself to a control-oriented phased approach that the thought of using trial-and-error puts professional managers ill at ease” (Lenfle & Loch, 2010, p. 32). The organisation and planning of major programmes have gone in the direction of an over-specification of objectives and targets from the onset, which is one of the causes of the inefficiencies of the projects, largely caused by the negative influence of ‘planning fallacy’ (Kahneman, 2011). In this sense, megaproject management as a discipline lost its original openness to the unexpected and the ‘unknown unknowns’ – which was a core value in revolutionary megaprojects such as the Manhattan Project in the 1940s (Lenfle & Loch, 2010) –, for a heavy reliance on accounting-based measures and myopic adherence to performance control. This induced an emphasis on the

Complete definition of the system before it is developed in order to limit uncertainty; lower uncertainty eliminated the need for parallel trials and experimentation. [...] [*This turned*] the tools into de facto standards for project management (Lenfle & Loch, 2010, p. 1).

In the light of these considerations, it appears that the engagement with accounting information and the attitude towards risk and the management of uncertainty are issues that not only strictly technical but are associated with behavioural issues that affect programme delivery and are influenced by institutional and political pressures (Hodgson & Cicmil, 2006).

A fundamental element that mediates these issues, which is connected to the production, interpretation, and action on the basis of delivery information, is the mode of presentation of the information in question (Quattrone, 2017). Megaprojects require procedures to simplify, integrate and layer substantial amounts of data to support decision-making processes at different levels of the program governance (Giezen,

2012; Van Marrewijk et al., 2016). Given the magnitude of such projects, visualisation of information is an essential aspect of delivery that can have an impact regarding cost containment, delivery times, and benefits realisation (Lenfle & Loch, 2010). Due to their inherent complexities, megaprojects are paradigmatic sites to investigate how programme delivery information is presented, and the roles that data visualisations can play as platforms for engaging with the emergent challenges of these settings. Additionally, as Anthony Hopwood (2005) argued, despite their economic, technical, and social significance, megaprojects are an under-researched area of study in accounting, and a more thorough understanding of accounting issues could provide valuable insights that are not only relevant for theory development but could contribute to tackling the poor performance of megaproject delivery.

In the light of this background, Crossrail was selected as the site to conduct the qualitative case study. While more precise details about the specificities of the reporting function and challenges in Crossrail²² are discussed in the findings, it is nonetheless informative to offer some broad background on the megaproject setting. This study was conducted in the Programme Controls Department of Crossrail Ltd., the delivery vehicle for the realisation of the Elizabeth Line, the new high frequency, high capacity railway for London, which is visualised below.

²² All the information in this descriptive section are publicly available from the Crossrail Learning Legacy (2018) website.

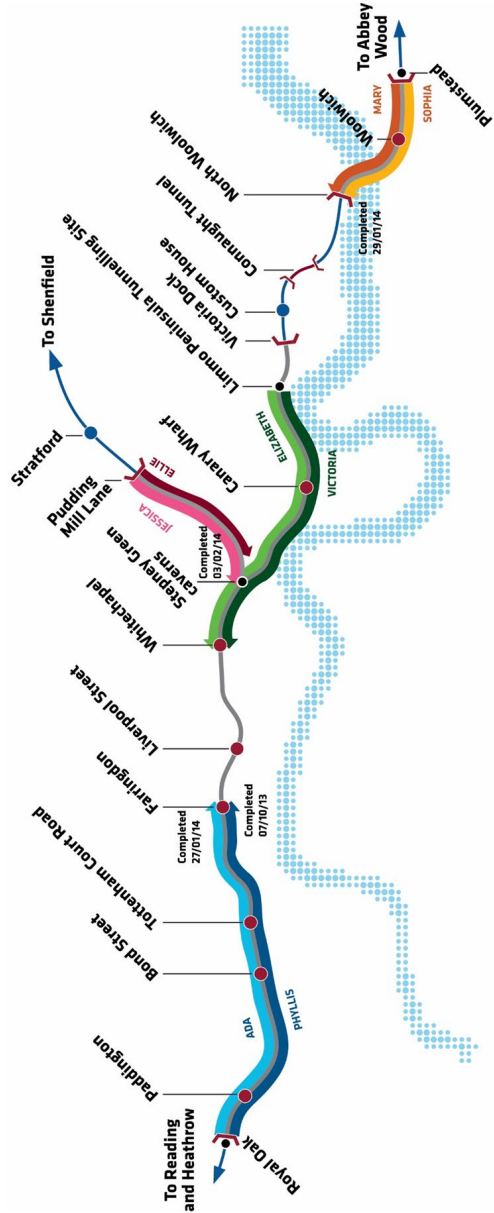
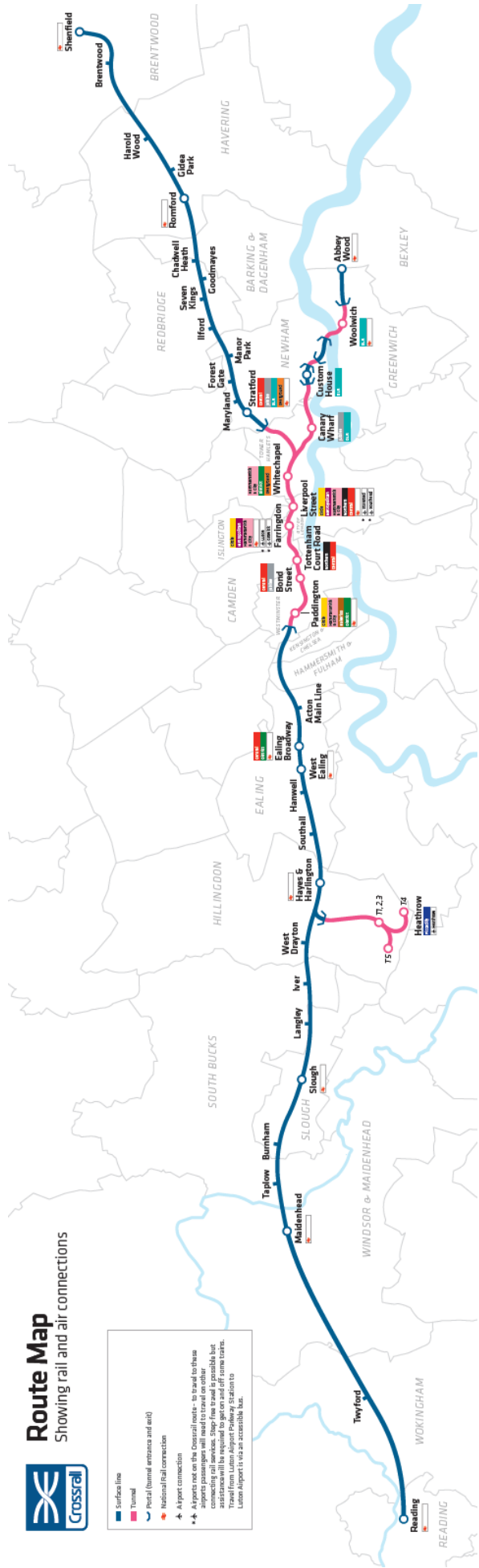


Figure 1. Crossrail route map with a focus on the Central London section (source: Crossrail, 2018)

With £15 billion funding and 14,000 people employed at peak, Crossrail is currently the biggest infrastructure megaproject in Europe. Crossrail is a 118-kilometre railway line under development in England, running through London to the home counties of Berkshire, Buckinghamshire, and Essex. The Crossrail Act was given royal assent in July 2008 and construction began on 15 May 2009. The central core and a large section of the line, between Paddington in central London and Abbey Wood in the south-east, are due to open in December 2018. The program will create 42km of new tunnels up to 40 meters under central London, requiring 12km of sprayed concrete lining. The realisation of the Elizabeth line entails the construction of 9 brand new stations in central London and significant structural upgrades to 27 existing stations. These upgrades will result in an increase of 10% in London's rail capacity, with up to 72,000 additional passengers per hour. Crossrail had a peak monthly spend of £140 million and is forecasted to realise £42 billion of economic benefit to the UK economy when operational. The Elizabeth line is now (June 2018) approximately at 90% completion and is scheduled to be finalised by December 2019. The project is currently on time and within funding (see NAO, 2014; Marrs, 2016; Crossrail Learning Legacy, 2018), and this makes it a notable world-class exception in megaproject delivery worldwide (Flyvbjerg, 2007, 2014).

4.3. Data collection

Having discussed the reasons underpinning the selection of qualitative case study as a methodology to conduct this dissertation, this section turns to the specifics of the data collection process and methods. This study relied on semi-structured interviews, document analysis, and visual analysis. Observation played a minor role in the data collection process. Access to Crossrail was negotiated to senior management, at Programme Board level. The Director of Programme Controls and a Controls Transition Manager were the first two points of contact for starting the data collection in January 2017. They later put me in touch with key individuals in other departments. Access to these departments and visits on construction sites was then negotiated based

on suitable timings depending on occasions of interest. Additional data collection opportunities were facilitated by the participants who progressively put me in contact with persons they deemed of relevance. In this sense, the approach to the selection of participants for the study could be defined – using Bryman & Bell’s (2011) terminology – ‘snowball sampling’, which is a technique for gathering participants through the identification of an initial set of subjects, who are used to offer connections to other actors, who in turn may open possibilities to expand the network of inquiry. This data collection strategy aims to overcome issues associated with understanding and sampling concealed populations and enables going beyond formal organisational structures by taking advantage of the participants’ web of contacts, which can offer the researcher an escalating set of participants.

The study relied on semi-structured interviews as the primary data collection method. A preliminary pilot study in the Programme Controls department was undertaken to develop a general sense of the accounting and management challenges that characterise the delivery of Crossrail. The pilot study focused on issues such as: The structure and cadence of the reporting cycle, the reporting and organisational hierarchy, identification of and reporting to stakeholders and sponsors, and the main challenges of programme delivery. This pilot included six participants – i.e., the Director of Programme Controls, the Head of Reporting, a Controls Engineer, a Board Member, an external consultant, and a Project Representative – and was also used to identify what, in their view, were the most influential reporting products that were used during the reporting cycle. While some of the interviewees were experts for specific technical issues of interest for this study, others were senior general managers and thus provided broader insights regarding the management of Crossrail. Additionally, from the pilot study, three visualisations emerged as particularly influential – namely the project dashboard, the programme dashboard, and certain visual aspects of the board report (that are discussed in detail in the next chapter). I was provided with copies of such artefacts, which were analysed visually, and their analysis guided the development of the interview questions. The interviews were coded through an iterative process, where the transcripts were read and listened to multiple times, to develop the final interview protocol for the following semi-structured interviews.

In total, twenty-eight participants were interviewed. Interviewees comprised participants at different levels of seniority in the following departments: Programme Controls, Planning, Quality, System Wide, Health & Safety, and Learning Legacy. Additionally, two Board Members, three members of the Executive Committee, three external consultants, and two members of the UK Government's Project Representative Team were interviewed. Several informal interviews were undertaken with participants from the sponsor organisations, namely the Department for Transport (DfT) and Transport for London (TfL). Additionally, throughout the data collection period – which lasted from January 2017 to December 2018 – ten follow-up interviews were conducted. These follow up interviews had a narrow scope and focused on the design process and features of the visual artefacts in question. Most of the follow-up interviews were conducted with participants from the Programme Controls department, as they are in charge of the design, development, production and implementation of most of the reports. In both the interviews the participants were asked to provide a physical or digital copy of the reports that they deemed to be of importance in their respective roles²³ (Greenwood et al., 2018; Rose, 2007). Table 2 below summarises the interviews conducted as part of this PhD thesis.

²³ A large part of these conversations focused on: (a) How they interpret and make sense of the visualisation; (b) how they use the artefact in question, (c) on which specific aspects of the visual they focus the most and why, (d) what are the features that they believe are effective and those that are not, (e) how they would change the layout and configuration if it was up to them. Conversations with participants that were personally involved in the design of the reports focused more on the rationale behind the inclusion/exclusion of specific features in the reports, and insights on the design process and design change over time in relation to the delivery phases and maturity of the programme.

Interviewee	Department	Number interviews & follow-ups	Duration of Interviews (Approx.)
Controls engineer 1	Programme Controls	4	1h; 30m; 30m; 30m
Controls engineer 2	Programme Controls	2	1h; 1h
Controls engineer 3	Quality	1	45m
Controls engineer 4	Programme Controls	1	45m
Controls engineer 5	Quality	1	1h
Controls engineer 6	Planning	1	45m
Controls manager 1	Programme Controls	2	1h 30m; 1h
Controls manager 2	Programme Controls	1	1h
Senior manager 1	Programme Controls	2	1h 30m; 2h
Senior manager 2	Programme Controls	3	2h; 1h 30m; 45m
Senior manager 3	Programme Controls	1	1h
Senior manager 4	Programme Controls	1	1h
Senior manager 5	Planning	2	45m; 45m
Senior manager 6	Learning Legacy	1	1h
Executive director 1	Technical	1	45m
Executive director 2	Health & Safety	2	1h 30m; 30m
Executive director 3	Executive Committee	1	1h
Executive director 4	System Wide	1	2h
Board member 1	Finance	1	1h
Board member 2	Board of Directors	1	45m
Project representative 1	Project Representative	1	2h
Project representative 2	Project Representative	1	30m
Project manager 1	Contractor company	1	1h 30m
Project manager 2	System Wide	1	1h 30m
Project manager 3	Health & Safety	1	1h
External consultant 1	Consulting firm	1	1h
External consultant 2	Consulting firm	1	1h
External consultant 3	Consulting firm	1	1h

Table 2. Schedule of interviews (2017-2018)

The majority of the participants from the Programme Controls department hold an accounting certification, although their educational background is diversified, ranging from different branches of engineering to psychology. Additionally, it is worth noting that the person responsible for the core of the dashboard design work in Programme Controls is a chartered experimental psychologist who holds a management accounting certification. As it will become apparent from the case, the coupling of

behavioural psychology and reporting design has influenced the layouts and configuration of visual artefacts. All interviews were digitally recorded and complemented by extensive note-taking. During the transcription, one of the interviews was found to be inaudible due to faulty equipment, and its core content was retrieved relying on memory and the notes taken during the interview. Additionally, data collection was also informed by informal conversations before and after the interviews, which offered further insights into the issues raised during the interview.

Semi-structured interviews are appropriate for an inductive and exploratory research approach. That is because they afford flexibility while offering a coherently organised structure to coordinate the interview process and to investigate different nuances of the research phenomenon. To exploit in full this research technique

It is essential to understand that interviews do not stand for anything else; they merely represent an interaction that is recorded or inscribed. That is all they stand for, and it is more than enough [...] the interview can be treated first, as an occasion for eliciting narratives (stories); second, as a special type of observation; and third, as an opportunity to collect samples of the prevalent logic of representation (Czarniawska, 2014, p. 30).

In the light of these considerations, semi-structured interviews are a valid means for the elicitation of diverse forms of knowledge and perspectives on a specific research issue. This technique allowed targeted questions while enabling the participants to express how they made sense of artefacts, visualisations and situations (Stigliani & Ravasi, 2012; Whyte, 2013; Whyte et al., 2016). A combination of introductory, follow-up, specifying, direct, indirect, structuring and confirmation questions were used to prompt elaboration and to gain precise as well as general insights into the issues under investigation.

One of the aims that guided the interview process was achieving ‘theoretical saturation’ (Bryman & Bell, 2011), namely a point in time in which additional and unexpected information was no longer emerging from new interviews, conducted following the same protocol. About research ethics, each conversation was initiated with a discussion regarding the research issues, goals, and a general discussion on the PhD project. After an overview of the project, each participant was talked through the information and consent forms. As a result, in some cases, the interviewees questioned the researcher on specific issues regarding confidentiality, privacy, and data; this contributed building rapport and was especially useful for junior staff members who were particularly concerned with anonymity. Another valuable data source for this project were reports, dashboards, internal documents, and PowerPoint presentations. Large parts of the interviews revolved around a discussion about this kind of artefacts, their design, and use. Among these types of materials, reporting information played the most significant role. In Crossrail, the reporting is articulated in a variety of reporting products. Figure 2 below contextualises these reports with the broader governance and reporting hierarchy of the programme.



Figure 2. Governance, reporting and controls in Crossrail. Source: Laws & English (2016)

As emerges from figure 2, there are six reports in which Programme Controls are involved: 1) Contractor dashboards, which are only partially standardised and are produced by contractors in the delivery of specific projects; 2) Project dashboards produced by project managers and Programme Controls; 3) Area director reports; 4) Informal programme dashboards for governance meetings; 5) The board report for non-executive directors; 6) Semi-annual construction reports for the sponsors. The project dashboard, the programme dashboard, the board report and specific features of the sector director reports emerged from the interviews as the most relevant artefacts on which to focus the attention of this study. That is because such visuals are those that, given their central role in the decision-making and governance processes, underwent the most significant design change since the start of the construction programme. The reasons why most of the focus of this case lies on those reports is because they are designed and put together entirely in Programme Controls (see the following Crossrail Learning Legacy papers: Warren & Laws, 2016; Laws & English, 2016; Palczynski, 2016). Other reports, such as the contractors' dashboards and the semi-annual construction reports, are designed on the basis of internal processes of contractors' companies or specific requirement of the sponsors. Hence, they are not necessarily representative of Crossrail's operational and decision-making concerns. Another significant, yet minor²⁴, source of data was the non-participant observation of the engagement with visual artefacts. Various teams of controls engineers and reporting designers in the Programme Controls department were observed in their office work and the implementation of design changes to the reporting templates. Not only insights from non-participant observation were valuable, but they helped the development of an appreciation of the multifaceted nature of the phenomena being investigated. The reason why a more ethnographically-oriented approach was not selected is that, as Whyte et al. (2016) argue, to explore these issues situated ethnographies are inadequate in capturing digitally mediated ways of working, as they can provide a limited understanding of how visualisations become elaborate and circulate in project organisations. Tracing connections among visualisations instead

²⁴ Some of the reasons that justify this methodological choice relate to the fact that, for example, for confidentiality reasons I was not provided access to Board meetings, which is on the privileged sites to explore how Executive and Non-Executive Directors engage with important reports such as the Board Report and the programme dashboard.

Extends the empirical focus beyond the ‘here and now’ of situated interactions, and challenges the assumption of privileged insight that comes from the anthropological roots of the ethnographic approach (Whyte et al., 2016, p. 116).

However, relying on observations was insightful in the identification of connections that constitute the everyday practices that inform the engagement with visual artefacts, thereby shaping interactions and forming the setting within which the research phenomenon is situated (Latour, 2005).

The last significant data source that informed this research project was public and internal documents. These documents comprised publicly available ones, including policy documents, opinion pieces and newspaper articles about the Crossrail megaprojects as well as several Crossrail-authored case studies (publicly available at the Crossrail Learning Legacy website), newspaper articles, and documents from the National Audit Office. These documents were used as preliminary sources and as a means of structuring the pilot interviews. Other sources for data collection were seven Programme Controls Webinars conducted by control managers in Crossrail (e.g., Laws & English, 2016; Palczynski, 2016). The research also drew from proprietary documents that were acquired through the interviewees and other contacts in Crossrail, including a variety of evaluation reports and governance frameworks. These documents were not only crucial for the understanding and appreciation of the challenges of designing visual artefacts in the broader organisational context but were central to the identification of issues discussed in follow-up interviews.

4.4. Data analysis

The first step in the data analysis process was the transcription of the semi-structured interviews. This aspect was important as it initiated the familiarisation with the data. As Czarniawska (2014) argues, field research is about collecting and producing texts. My field study developed along these lines: After each interview was transcribed,

drawing from the notes taken during the interview, a commentary section was added to each interview file. This additional narrative element accounted for factors which ranged from body language, tone, and emotional responses connected to the discussion of specific issues, anecdotes, and management challenges – as well as providing a record of the mental associations that were prompted during the interview. The additional commentary was invaluable in connecting the interviews with the artefacts being discussed. Statements such as “I first look at *this* feature”, “then at *that*” and “I never consider *that*” were frequent and the commentary was fundamental in the identification of the referents of such ostensive definitions. Given the effort in trying to integrate interpretation, narrative elements and visual features of artefacts, this process was fundamental for the identification of codes, which helped to identify and group together “incidents, events, or pieces of conversation related to a particular theme” (Bryman & Bell, 2011, p. 391). The aspect of writing commentary and narratives particularly important, as in field research

There is more to it than ‘just talking’. [...] Texts are actions (strictly speaking, material traces of such, but they result from action and provoke further action), and actions are texts in the sense that they must be legible to qualify as action (Czarniawska, 1998, p. 11).

Accordingly, in building the narrative in the case study, I focused not only on interviews and texts as expressed by organisational actors but also to actions generated by visualisations that were observed in the site. Upon completion of the transcription and the preliminary analysis phase, the data analysis proceeded in the following activities: Analysis of data from informal interviews, observations, and pilot study; analysis of interview data and follow-ups; visual and document analysis; additional analysis of the data and triangulation. All these phases were not strictly chronological but iterative and they mutually informed each other. In this sense, the analysis was conducted moving back and forth between the field and the desk (Czarniawska, 2014). This helped making sense and interpreting the data and its connection with existing insights from the literature, thereby these several iterations continuously informed and

refined the ongoing process of data collection. The process of data analysis can be divided in four different aspects that mutually informed each other, as shown below.

Activity	Intended Outcomes	Achieved Outcomes
Analysis of data from informal interviews, observations, and pilot study	<ul style="list-style-type: none"> • Exploration of themes and relationships <i>in situ</i> • Development of final semi-structured interview protocol 	<ul style="list-style-type: none"> • Observation of sociomaterial practices • Identification of themes and issues to be explored in interviews • Interview protocol
Analysis of interview data and follow-ups	<ul style="list-style-type: none"> • Exploration of the participants' views on the identified themes and relationships • Emergence of new and unforeseen themes • Insight into the design (i.e., principles) and practice of visual artefacts (i.e., use) 	<ul style="list-style-type: none"> • Relationships with observational data • Direct account of design and practice of visual artefacts • Visual features deemed influential in use • Account of theoretical and pragmatic design concerns
Visual and document analysis	<ul style="list-style-type: none"> • Insights from categorical analysis, content analysis, rhetorical analysis • Identification of reoccurring visual features 	<ul style="list-style-type: none"> • Discrepancies and similarities with interview data • Insights into the formal features of artefacts • Identification of aesthetic codes
Additional analysis of the data (i.e., aggregation of insights from other activities)	<ul style="list-style-type: none"> • Triangulation between observational data, interview data, and visual analysis • Development of second order themes 	<ul style="list-style-type: none"> • Aesthetics and functionality in design • Identification of resistance • Analysis as presented in the findings

Table 3. Phases of data analysis

Data analysis software was not used in the various analysis activity detailed in Table 3. The analysis was conducted manually, following a precise procedure. After the addition of the commentary, all interviews were printed in a single-sided format with double-spacing and large margins to maximise physical space for annotation and additional analysis. Notes were taken during the multiple reading iterations. At each note-taking phase and a different pen was used to distinguish one iteration from the

next – this had the purpose of distinguishing my thoughts at different points in time. The notes had the purpose of tentative open codes. Manual colour-coding of emerging themes was done consistently relying on highlighters, which were useful to flag unusual elements for further examination. The analysis proceeded to order the materials further chronologically to facilitate orderly identification of themes and patterns (Ahrens & Chapman, 2006).

All the highlighted sections were then copied and pasted into a table, coupling codes, citations, and second-order codes. This table grew with the increase in interview transcriptions and analysis; together with it, tentative labels and titles were progressively updated. An additional table was created, which contained quotes associated with each visual artefact being analysed or individual features of an object. The purpose of this table was not only to guide the analysis but to provide cross-cutting insights that could avoid the risk of ‘black-boxing’ associated with coding and thematic analysis (Czarniawska, 2014). Once this process was completed for all the interviews available, the most insightful quotes were copied into a new file in a cluster format, in an attempt to classify them with a tentative label. The outcome of this process ultimately is the case study itself, and its thematic sections.

Each round of analysis followed a similar three-level coding process (Flick, 2009). This enabled me to develop a sharper theoretical focus over time. The idea that the design and practice of data visualisations shape interactions and interpretations by means of the affordances of visual artefacts emerged as an outcome of the different iterations with data detailed in Table 3. Over time, this process led to the emergence of the differentiated focus on the design and practice of data visualisations. The identification of design and practice of visualisations as aggregate dimensions emerged as relatively clear cut during the analysis process. While a small sub-group of participants are both designers and users of reporting information, the specific design activity is conducted among a very small number of people in Programme Controls. Accordingly, the separation of design from practice had the advantage of being intuitive while resonating with the fieldwork and formal features of the Crossrail

programme structure. Table 4 below offers a summary such twofold dynamic by detailing the aggregate dimensions, second order themes and first order concepts.

Aggregate dimensions	Design of visualisations		Practice of visualisations	
<i>2nd order themes</i>	<i>Inclusion and exclusion of features</i>	<i>(Intended) affordances</i>	<i>Enabling features and practices</i>	<i>Constraining features and practices</i>
1 st order concepts	Executives' preferences	Understanding the 'bigger picture'	Understandable visual designs	Dashboards hide things
	Inventory of concerns	Intelligibility	Minimalism	Fast-evolving programme
	Needs of specific users	Prevent information overload	Manual intervention on visualisations	Behavioural issues (e.g., optimism bias)
	Colour coding and weighting	Desire to engage with artefact	Aesthetics	Time consuming
	Consequences vs. antecedents	Driving behaviour through visualisations	Populating the dashboard	Comfort pictures
	Memorable features	Comprehensive evaluation	Semi-automatic production	Many design iterations
	Translation into a visualisation	Subitizing and dwelling	Routine of dashboard production	Risk of oversimplification

Table 4. Data structure.

Initially, the empirical material was analysed trying to identify how designers shape the practices of future use of the artefacts they construct. However, this quickly emerged as a simplistic approach as the designers themselves recognised that what they are in control of is simply the inclusion and exclusion of features from layouts and reports, and what the artefact will afford can only be 'hoped-for'. In this sense, the material aspect of including and excluding design features was separated thematically from the intended affordances. What this means is that, while both inclusion and exclusion of features and intended affordances are design concerns, the reflection on

intended affordances is a speculation of the designers and cannot be assessed without reference to the practice of visual artefact.

The belonging of concepts to second order themes occurred through the analysis and observation how and why certain features were added to reporting products. For instance, factors such as the fact the Programme Director pushed for the adoption of a highly visual reporting function or the concern with ensuring that the users can see a comprehensive set of indicators directly influenced the design of dashboards and reports. The belonging of concepts to the ‘intended affordances’ theme emerged through the progressive isolation of the interactions that the designers were hoping to achieve by deploying specific features. For instance, the material inclusion of colour coding and memorable shapes and patterns was aimed at achieving that users would more quickly understand the ‘bigger picture’ of programme delivery and that they would not be overwhelmed by the information content of visual artefacts. The identification of the second order themes of the ‘practice of visualisations’ dimension was developed focusing on how specific features of artefacts and sociomaterial practices are perceived by the users as enabling or constraining.

The analysis of the interviews was coupled with the visual material collected in the field. Visual elements are of great methodological importance, as they are “articulations of human experience in specific times and places and represent a significant materialisation of the norms and concerns of people” (Brinkman, 2012, p. 131). In the interdisciplinary accounting research area, visual analysis has been applied mostly by scholars who investigated the visual rhetoric of annual reports (Davison, 2015). As Meyer et al. (2013) and Greenwood et al. (2018) argue, within the existing visual methodology literature, scholars mostly focused on modes of visual data collection rather than on their analysis. However, the analysis of visual images and artefacts can yield meaningful results, as visual elements are often first to attract readers’ attention and appeal to intuitive and synthetic rather than analytical reasoning (Kahneman, 1974; Tversky & Kahneman, 1986; Anderson, 1980). Additionally, they are involved in the emphasising or diverting attention from particular aspects of text

or data (Berinato, 2016), and can work as prompts for interpretation (Boland, 1989), sensemaking (Stigliani & Ravasi, 2012), the invention of knowledge and creation of associations (Quattrone, 2015a). However, as Greenwood et al. (2018) argue, there is a ‘theory-procedure gap’ in visual methodology:

Theory-driven approaches draw upon a range of philosophical, linguistic, and aesthetic perspectives. Research studies or methodology texts in this vein tend to be conceptually dense, sometimes with a lot of jargon, and dependent upon the individual researcher’s internalized comprehension of the theoretical framework in use. [...] By contrast, procedure-driven approaches [...] are often more transparent about research design choices and analytical procedures and are thus more easily replicable. However, there is typically little or no a priori discussion of the theoretical status of visual data, or findings generated, with such approaches (Greenwood et al., 2018, p. 3).

The analysis of the visual material in this dissertation was conducted trying to mitigate the polar opposition in visual methodology illustrated by the quote above. To do so, the analysis of visualisation was conducted relying on the notions of affordances, visual conventions, and visual literacy that were theorised in the previous chapter as *explanantia* to guide the analysis.

These concerns were combined following the three steps approach proposed by Greenwood et al. (2018). Phase 1 was concerned with the categorical analysis, namely a procedure-driven approach that aims to describe and explain a visual artefact and – when relevant – the whole document in which it is situated. Phase 2 was concerned with the content analysis, namely the description of visual phenomena in the different documents in the data set, focusing on aspects that are related to the perceived artefact and the cultural aspects of the artefact. Phase 3, was concerned with the rhetorical analysis, focusing on the argumentative function of visual material by analysing its connotative context of shared cultural understandings across a variety of visual artefacts, interview material, and observation outcomes (Greenwood et al., 2018). In this last phase, particular focus was placed on how the features of a visual item perform the following rhetorical functions: Guiding the interactor through the artefact, focus

attention by putting emphasis on features, increase impact regarding the interactor's judgement on the importance of a topic, illustrate visually relationships among elements, provide context and tone (see Greenwood et al., 2018; Kress, 2009).

This approach to dealing with the visual material is consistent with the aim to explore the relationships between interactors and artefacts in terms of matters of concern instead of matters of fact (Latour, 2005). Conceptualising the study of the materiality of organisational artefacts and how they unfold in practice as matters of concern not only recognises the multifaceted role of agencies in an empirical setting but also seeks to embrace the richness of different associations that exist between actors in the setting. Hence, following a narrative strategy to hold together and engage with heterogeneous data sources is appropriate to appreciate the inherent multiplicity of beings and relationships in the setting (Czarniawska, 2014). This approach, based on the joint analysis of the visual material, the interview transcripts, the narrative commentary and insights gained from observation aimed to offer a comprehensive account of the design of accounting visualisations in Crossrail. As outlined in the previous chapter, these concerns and the research approach is compatible with a sociomateriality framework, which provides a relational ontology that affords to account for the constitutively entangled nature of artefacts, people, and practices (see Orlikowski, 1992, 2007; Leonardi, 2011). Sociomateriality

Refers to the entwined nature of the social and the material. [...] Sociomateriality highlights the nexus of doings, materialities, and discourses that people carefully enact. It offers an analytical perspective from which neither artefacts, nor people, nor practices are seen naked and alone, revealing solely their inherent properties. Instead, people, artefacts, and practices are bound together into one entity within networks or assemblages with dynamic boundaries (Bjørn & Østerlund, 2014, p. 8).

Coupling these considerations with a focus on design and the notions of affordances, visual conventions, and visual literacy enabled a theorisation which capitalises on the

advantages of the purposeful design-oriented research tradition (e.g., Simon, 1996), which

Strives to draw theoretical approaches into the practices of designing artefacts to ensure that work practices and artefacts remain synergistic [...]. Understanding practice with the aim of designing, implementing, and adapting artefacts to be enacted in particular organizational practices is a critical path crucial for design research (Bjørn & Østerlund, 2014, p. 8).

One last point that remains to be clarified regarding the analysis of the data and their synthesis in a qualitative case study relates to ethical considerations regarding the how accounts provided by participants are represented in the findings. In this sense, it is important to reiterate that the same research phenomenon could be analysed in ways that would represent the dynamics of the setting differently. As Czarniawska (2014, p. 123) argues

A skilful description depends heavily upon metonymy and synecdoche – on deleting some information – in the hope that readers will fill in the blanks, which should also increase their engagement in the reproduction of the text.

Recognising that there is an impossibility of faithful representation implies that there is a lacuna in any account, and such a lacuna cannot be closed (Quattrone, 2006). This, in turn, reinforces the importance of the way through which the account is constructed by making evident that every account is based on *capta* (Drucker, 2011) and is as a form of presentation that always implies a reduction which is to an extent arbitrary. Considering these concerns, the approach towards data analysis and presentation in this project is guided by the aim to balance these ethical and methodological concerns reflexively.

4.5. Concluding remarks

Based on the philosophical considerations regarding the notion of sociomateriality outlined in the previous chapter, this section on methodology has discussed how the research was carried out. The chapter justified the selection of case study methodology and its validity for the exploration of issues pertinent to the design and practice of visual artefacts. It was argued that the proposed methodology enables an in-depth and nuanced understanding of the phenomenon under consideration. The chapter then turned to a discussion of the epistemological status of the knowledge that can be developed relying on qualitative case studies. Mobilising Agamben's (2009) notion of paradigmatic case, this chapter aimed to shed light on how it is possible to learn from cases, highlighting how such learning is neither general nor context-specific. Following this, it outlined in which sense infrastructural megaprojects ideal sites to explore how visual artefacts become performable in the engagement with complex settings. The data collection section explained how semi-structured interviews, document and visual analysis, and observation were designed and used to gain a fine-grain account of the roles, function, and reporting design process in Crossrail. The data analysis illustrated the coding techniques and approach adopted in the thesis and focused primarily on how insights were obtained from the analysis of the visual material. The thesis now turns to the empirical findings.

5. CASE STUDY

5.1. Introduction and overview

This chapter presents the evidence from the fieldwork that was conducted in Crossrail as part of this PhD project. In doing so, the research is guided by several key concerns. The review of the literature showed how the design of accounting visualisations remains an under-explored area of research and affirmed the importance that aesthetic and functional design considerations have in the construction of visualisations that aim to support the engagement with complex and dynamic organisational settings. The theory chapter illustrated how, drawing from the notions of affordances and visual conventions, it is possible to shed new light on the study of the visual in accounting. In fact, the abovementioned concepts can inform the exploration of how designers rely on specific features to pre-empt interaction and govern the rhetorical relationship with organisational artefacts. The study of how designers deploy conventional forms in the hope that specific artefacts will convey the intended affordances offers promising insights into a distinct approach towards the study of how visualisation become influential in their domains of application.

To explore these concerns, the chapter is structured as follows. The first section of the case study is concerned with a general overview of the challenges that characterise the reporting function in Crossrail. The second section explores more specifically the *reporting ethos* of the Programme Controls department, paying attention to how the visual aspect of reporting is understood in the organisation. Building on insights from these sections, the third one explores the design features of specific dashboards designed in Programme Controls. In so doing, its focus lies on notions of multimodality and the criteria adopted by reporting designers in the construction of specific artefacts. The fourth section investigates how designers strive to adapt visualisations to the always-unfolding nature of megaproject delivery. The fifth section focuses on how data visualisations can be implicated in bridging the elusive gap between reporting and action. In so doing, it investigates how visualisations are

designed to function as ‘behavioural tools’ and the main factors that enable and constrain their practice. The sixth section focuses on the roles of discernible and memorable visual patterns as design characteristics of performance visualisations. By illustrating how the ‘worm diagram’ is deployed in a consistent manner in different artefacts, it investigates how the design features of visualisations can facilitate the creation of associations, help users develop a sense of the ‘bigger picture’ of programme delivery, and support the consolidation of visual conventions.

5.2. The reporting challenges in Crossrail

The objectives of this first section of the case study are to contextualise Programme Controls’ purpose and provide an overview of the principles that guide Crossrail’s reporting function. Additionally, this section illustrates how reporting design, and especially its visual components, are believed to influence the understanding that users have of the reporting information presented to them.

The objectives of Programme Controls in Crossrail are to:

Provide accurate information on the programme, act as the conscience of Crossrail, and provide performance analysis to support decision-making [...] in connection with the four objectives: Are we safe? Are we within funding? Are we on time? Are we world class? (controls manager 1).

The Programme Controls function is concerned with the activity of producing a series of reports, which entail specific challenges and are targeted at different audiences. Additionally, the department has a fundamental role in the presentation of accounting and programme delivery information to different stakeholders.

In the Programme Controls department, we are accountable for the collection of all information at all levels for the entire programme, which is interrogated every four weeks to be validated to make sure that all projects are reporting

accurately and turn it into a format that is readily understandable by the executive directors' team and sponsors. The challenge for us is that we have a huge amount of information, a lot of it is very granular and doesn't make sense if do not know a lot of delivery-related details. So, turning that information into a format that tells senior management what they need to know to be fully briefed and to allow them to be effective decision-makers, that is the art of what we do (senior manager 1).

As the quote suggests, the design of the reporting products is complicated by a series of interrelated issues. Constant trade-offs regarding the specificity of information, its integration, presentation and visualisation, and the temporal needs and constraints of the reporting cycle are fundamental for the reporting function. According to a board member:

The great challenge when you are dealing with a project of this scale and size is how you filter the sheer quantum of information that is generated across all the individual projects and contracts that we have across the business, and filter that down into something that is workable and usable across the organization (board member 1).

To design reports that are effective in supporting the engagement with the challenges of megaproject delivery, controls managers in Programme Controls pay attention to how to filter information to maximise the usability of different reporting products. The magnitude of the megaproject and the amount of information produced by the departments require carefully thought through reporting criteria. The identification of such criteria is not straightforward:

Consistency in approach is one of the main challenges in terms of formatting and design. People have different preferences [...]. There is an element of translation into the correct design which needs to be addressed. [...] In terms of the ambiguity and lack of understanding of the data, by the time something gets to programme level, everything is aggregated, so it is difficult to draw conclusions based on detailed level information. One needs to be very clear about how to present data and make sure people have an adequate understanding of what it all means (controls engineer 1).

The design specifications of Crossrail's reports are concerned with the selection of information and its mode of presentation, which are related to the *supra*-textual level of the reporting documents, the *intra*- and *inter*-textual levels and the *extra*-textual level²⁵ (Kostelnick, 1988, 1996). The articulation of the design of the reporting products along these levels, which are different in each of the reports, aims to achieve the following goal:

[*Preventing reporting from falling*] into a vicious loop. If reporting is seen as a chore – an administrative, low-value overhead – the product will be low priority and passed to more junior or less skilled staff. The end product will lack powerful, consistent, well-crafted content. The reader will not learn useful new information; content will be inconsistent or inaccurate. The report will not be used to facilitate effective governance meetings and become disconnected from discussion and decision making. The report will be read less and few if any questions will flow back down the organisation. Ultimately, the producer will deprioritise production and see it a chore (Crossrail, 2016, Board Reporting, unpublished internal document).

To avoid this 'vicious loop', the reports were designed with the needs of specific audiences in mind, paying attention to the degrees of detailed knowledge of a specific context and the need of different user groups to develop an overview of the programme. According to a senior manager that was responsible for the ideation and design of most of the reporting products developed and used in Crossrail:

There are several traps underlying this issue. The narrow functional specialists that create specific content of course understand the detail but forget or can't conceive that others don't. Human nature means people are often reticent to ask 'what does this mean?' or sub-consciously think 'I don't know what this is... therefore it can't be important'. [...] Another trap is the 'not invented here' syndrome, which is exacerbated by organisational silos: Finance thinks the

²⁵ The *supra*-textual level relates the overarching design of the reporting documents, which encompasses the arrangements of the *extra*-textual features (e.g., design of data displays) within the report and regulating its internal flow (i.e., the layout) with the aim of creating a coherent document (Kostelnick, 1988; 1996). The *intra*-textual level is "coded primarily in the alphanumeric/symbolic mode and controls the local form, size, posture and embellishment of textual elements" (Kostelnick, 1988, p. 32), whereas the *inter*-textual is "coded primarily in the spatial mode, generating visual cues that enable [*interactors*] to search for and retrieve information" (*Ibid.*). The focus of this case lies primarily on the connections existing among the *supra*- and *extra*-textual levels, and their significance regarding the creation of interfaces with interactors.

finance pages are the most important; Commercial the commercial pages, and so on (senior manager 2).

One of the fundamental criteria that Programme Controls managers adopted to avoid and prevent issues such as the above was to design of each of the reports “working backwards from the audience’s needs” (senior manager 2). This was motivated by an effort to foresee the challenges that people face in their roles and focusing on what is believed to be the core delivery information they need to know. However, this process is problematic because of the intrinsically ambiguous relationship between designers and users. This, in turn, is reflected in the deployment of features that aim to pre-form interaction in a way that facilitates interpretation for the specific user groups in question. For example, in the case of senior decision-makers, the following factors are considered particularly important:

The data that we present to the board must be in a format that they can understand. This is a very large project, dealing with many, many areas of civil engineering, electrical engineering, operations, integration, testing and commissioning, etcetera. Not all our board members are experts in all those fields, so it is about making sure that the information that we present is credible and intelligible for them. [...] One of the main challenges is making sure that we communicate in the right way for the different audiences. For some audiences, such as the sponsors, we have to use words. [...] It’s critical how we do the translation. Our board report is highly visual, but the front section, which is probably the section that they read most, is a combination of visuals and words (senior manager 3).

In the light of the evidence above it appears that the design of reporting products is regarded as a worthwhile effort that is believed to play a crucial role in supporting the users’ interpretation and understanding. This process is adapted to consider the personal preferences of senior executives and is coupled with more ‘impersonal’ considerations of what reporting designers in Programme Controls deem to be the information needs of the audiences. A significant aspect of the design effort resides in the identification of formats and templates that can facilitate the engagement of different user groups. This concern is translated into the design of the reports not only trying to consider the constraints in the interpretation of information that a user group

may have but also providing explanations for the interpretation of project delivery information. In this sense, the trade-offs between understanding and the need for explanation is particularly complex:

A constant issue may be a lack of understanding and explanation. The core content of a report will be complex because megaprojects are complex. However, too often reports are produced with no attempt to explain the content, the context, the goals, the terminology or how to read the data and graphs. The report and the executive that presents it must clearly define good and bad performance, explain why something is good or bad, and help the readership interpret the information, not just accept the statements in the report as fact. For those new to the project or working as Non-Executive Directors and therefore not living and breathing the project, or simply reading content outside of their areas of expertise, this lack of explanation creates a major barrier to access, understanding and insight (Crossrail, 2016, Board Reporting, unpublished internal document).

The coupling of explanation and design is considered of great importance in Crossrail. As the piece of evidence above suggests, the Programme Controls department is concerned with the creation of reports that stimulate questioning and interrogation of the information provided. In this sense, the design effort does not necessarily aim to *simplify* the reporting procedures or content; rather it aims to aid interpretation, clarify the meaning of the parameters in question, and stimulate the questioning of why specific information is reported. In this sense, the objective is not to trivialise the content of the reports but to develop the visual and technical literacy to interpret them successfully (Ferguson, 1991; Messaris & Moriarty, 2005). The extract from the internal guidance document for the board report above places emphasis on the fact that it is paramount for the designers to ensure that Non-Executive directors (i.e., board members) question the ‘matter of factness’ of the reported information. In this sense, this core value of the reporting function in Crossrail can be interpreted as an effort to strive to conceive of accounting systems as engines that frame issues as matters of concern instead of merely serving as an ‘answer machine’ (Burchell et al., 1980; Quattrone, 2015b).

This introductory section highlighted some of the fundamental challenges for Programme Controls, paying attention to high-order trade-offs that emerge in the aggregation of information produced in the reporting cycle. The next section explores the visual aspects of Crossrail's reporting function and the ethos that characterises reporting in Programme Controls.

5.3. The reporting ethos of the programme

The design of reports that can stimulate the interest of the relevant user groups is connected to the development of visual formats and templates that go beyond the presentation of reporting information in standard data tables and text. According to the Board Member who is responsible for the Finance function (which includes Programme Controls):

If we deliver the reports in the traditional fashion, which is to have a lot of text, numbers and bullet points, it would make the document much harder, and effectively not user friendly if not actually unreadable, so not as useful in making sure that people would understand what we're trying to convey as the key messages, and the areas that they should be looking at, and the areas that are being dealt with. In the last three or four years with Crossrail we've been very actively trying to make sure that we push the report that isn't just a massive document, but is a document that is sufficiently in-depth, that they do get the important messages and understand the reasons why those messages are being conveyed, but the same time it's a usable document that someone can reasonably review, and assess, and make a comment on, if they've spent a couple of hours reading it beforehand (board member 1).

The process of progressively reducing the amount of data tables and text produced in the reporting cycle to design more compelling reports that leverage on the advantages of visual modes of presentation had a significant impact on Crossrail. As will be discussed in the next sections, one of the most critical ways in which Programme Controls currently perform their function is by relying on visual conventions that are believed to support and inform the design of accounting and reporting visualisations in the programme.

5.3.1. “If in doubt, draw a graph”

The reporting ethos of the organisation is captured effectively in the following quote from senior manager 2:

Here in Crossrail we are great believers in the phrase ‘a picture tells a thousand words’, and you need to use it to see trends and look for the outliers, and the best way of doing that is to draw a picture. [...] The ethos of ‘if in doubt, draw a graph’ helps you understand the situation, identify issues and communicate them.

As the essential piece of evidence above suggests, the design of the reports is not considered a merely aesthetic endeavour; instead, it is sustained by the conviction that visual artefacts can extend the ability of individuals and groups in processing content, reflecting on situations, communicate information and supporting reflexive engagement with accounting data. This approach is not coincidental and relates to the observation that making sense of visual material can be more effective and quicker than other modes of presentation:

The reason why there is a great push to have visual presentation is that of the lack of time, the constant delivery requirements, the constant change. Having visual representation allows you to process information sometimes faster, to see trends, your mind can map things in a different manner versus reading. [...] People at board level prefer something visual because they can look at it and see a pattern. And they don’t have to really read the data, analyse the data, and infer from it what they should be seeing. [...] The board is spending about two days every four weeks reviewing the contracts. Imagine if they didn’t have these visual diagrams showing, one, the change, but two, a pattern, they would have to read lines and lines of text. If they have to read lines of text, it would take longer than to look at something and see the difference (controls engineer 2).

As the evidence suggests, part of Crossrail's reliance on visualisations is due to how the visual mode can facilitate quick and confident information processing (see Pollock & Campagnolo, 2015), especially in relation to the needs of senior managers who have crucial remits, limited time, and vast amounts of information to process to be effective decision-makers. However, this reliance on visuals is not only connected to functional criteria such as the one reported by the controls engineer above.

Another critical factor that influenced Crossrail's visualisations was the personal areas of interest of senior manager 2, the former Director of Performance, and the person behind most of the visual designs that will be discussed in the next sections. He was tasked with reforming the reporting function with the support of the former Finance Director, and when asked about the intellectual background based on which he conceived of the role of visualisations in megaproject management, he said the following:

I can pinpoint the exact moment of my professional life when data visualisation became a thing, if not the thing. It was when I found the book by Tufte on data visualisation. 'The Visual Display of Quantitative Information'. I remember finding it in the Deloitte library and read it cover to cover, and that was the moment when it all crystallised in my mind, I kind of knew most of it, but hadn't articulated it. Literally, from that moment on it was something that I read more about. I read all Tufte's books, and the dashboard books by Stephen Few, but all the classic books on both how to communicate clearly, but say the books by Nancy Duarte. And then more recently, say David McCandless, and his 'Information is Beautiful'. So, they were the inspirations that I've looked to in terms of how to communicate numbers clearly, and then tell stories. It is not just data I should say. All of this informed the work I did in Crossrail and the ethos I tried to push for (senior manager 2).

The profound theoretical as well as applied knowledge of some of the seminal works on design and information visualisation that characterise certain control managers, as will be shown, had a profound impact on reporting design.

5.3.2. Executives' preferences and the adoption of visual practices

Another important reason behind the adoption of visualisations relates to the legacy derived from previous experiences and lessons learnt from senior executives, but also from their personal, and to an extent idiosyncratic, preferences. According to a senior manager:

We have a Chairman, and a Chief Executive who are good with words, so they don't need scripts. They use the pictures, and then they just can speak, because they can interpret that for the different audiences. [...] When you have very competent staff who can speak to images, it helps. Our Project Director [...], who led the hugely successful Olympics project delivery in the UK, would use dashboards extensively, so I think his influence has been heavy in terms of moving to more, and more dashboards and visuals. Because it's such a complex project, not everyone can know everything, but he needs to have awareness, so he has a critical issues tracker, then dashboards are very helpful. It was quite a lot of his influence that brought about this emphasis on visuals (executive director 3).

Crossrail's use of visualisations is explained by a drive from the top of the organisational hierarchy as well as by the advantages that a visual mode of presentation is thought to have over reporting of performance in data tables. Additionally, visualisations are believed to be helpful to capitalise on the experience of senior decision-makers. Visual reports are interpreted as a precondition for executives to form their professional judgement on the information provided – data which would not be manageable if it was not condensed into a visual. In this sense, visuals may help to capitalise on the executives' experience, rather than merely relying on interpretations filtered by their teams:

The volume of data is such that no one person can digest it all. The people that are genuinely familiar with the numbers that double-check and aggregate them are never really senior. Regarding the actual decision makers, there was no way that they could directly see the numbers themselves if they didn't have visualisations. [...] They would be purely reliant on their team, and the team's team, to provide the commentary and interpretation. Of course, you hire great people to tell you the messages, but, if you look at a one-pager from the board report, without visuals it would contain ten thousand data points [...]. It's too complicated not to have the visualisation, and by having it you can see it

yourself, you're not reliant on someone else telling you 'it's ok, don't worry.' If you don't see it yourself, you're purely reliant on someone else's judgement of what is acceptable and obviously depending on the culture that you have in the organisation. And by culture, I mean is this a 'good news culture' or 'bad news culture'? Are you allowed to say 'we've got a problem' before it's self-evident? (senior manager 4).

As the evidence suggests, the construction of visualisations that aggregate the information produced is regarded as a precondition to making it actionable. Not only the evidence shows that visualisations can enable the perception at a glance of what may take paragraphs to explain (Morrison & Wensley, 1991), but the simplicity afforded by the visualisation may augment the information portrayed by facilitating its processing (Pollock & Campagnolo, 2015). These considerations not only support individual information processing for senior executives but also appears to be a precondition for experienced managers to develop informed opinions on the information provided, as opposed to relying on the interpretations offered by their teams. Hence, data visualisation is understood as a means to capitalise on the knowledge of experienced decision-makers. In this sense, the engagement with visual artefacts can contribute to indexing further unarticulated or tacit knowledge of the interactors (Henderson, 1995).

5.3.3. Tensions and cultural drivers behind the practice of visualisations

The organisation of the reporting function around visualisations was not a process that occurred spontaneously. There was a cultural driver that followed the reorganisation of reporting around the four Crossrail objectives (i.e., safety, time, funding and world-class performance) that occurred from 2014. According to a board member, behind the use of visualisations in the organisation

There is a very deliberate driver. Culturally the business, over the last four years, has been focused on providing information in a way that does make it usable. [...] The templates have evolved. [...] When Crossrail decided to really

focus on those four banners: On time, on budget, delivering safely, and world-class, and then went through a process of understanding what is needed to be able to answer those four key remits of the project, and then starting to think how do you present that? [...] I think it helps a lot the communication element. I can look and read it, but then I can understand the scenarios where graphical interpretation can be a lot quicker and more precise to look at. So, if you have graphical output, it does give a stronger impact on differences between different projects, different areas that you're reporting (board member 1).

Hence, the centrality of the visual aspect emerged as a consequential answer to the newly defined remit of the programme around the four Crossrail objectives, as an attempt to clarify and supporting thinking, reflecting, and focusing on the central objectives and performance concerns of the megaproject. Although this visual focus is now established in the organisation, the reliance on reporting visualisations is not treated as an unproblematic aspect and there is scepticism and resistance towards this ethos. In fact,

The classic phrase 'pictures tell a thousand words' is true only if you know what the picture is. The pictures here are very impressive, but we have to use them to explain what the situation is. That is because we could use a picture saying 'look, isn't this marvellous, we've achieved this', but actually what we're showing is 'this is what we've achieved at one station, but we cannot achieve it at another because the supplier has gone bust', or something. So, what I found here is there's a heavy reliance on using images and dashboards rather than words, but for our board we also need words. Because dashboards can hide things, because you expect a sort of summary level of an issue, and unless there's a statistical thing that sits behind whether it's a red, amber or green status, it's a person's estimate, and that can only be the best estimate, and things change (senior manager 3).

Dashboards, because of how their designs pre-form their information content (Stark & Paravel, 2008; Kaplan, 2011) systematically and inevitably 'hide things', thereby creating and crystallising non-neutral forms of visibility (Qu & Cooper, 2011). Every possible visualisation creates a partial and value-laden picture that emphasises the visibility of specific aspects at the expense of others (Bloomfield & Vurdubakis, 1997), which influences the perception that managers have of specific situations. This, in turn, relates to the issue mentioned before about the role of visualisations in enabling

executives to form their personal opinion on a vast amount of information. These concerns are important because they highlight the problematic nature of the process of visualising information and its implicit assumptions (Drucker, 2011). Connecting the scepticism expressed by senior manager 3 with the previous quotes from board member 1 and senior manager 4, it is possible to make a fundamental tension emerge.

The evidence points towards the assumption that the designers' activity of visualising information to be qualitatively different from the partial and unidirectional activity of being briefed by a team member. However, although it is indisputable that visualisations can facilitate processing of accounting information (Desanctis & Jarvenpaa, 1989; Cardinaels, 2008), the pieces of evidence above seem to (paradoxically) attribute 'rhetorical neutrality' (Kinross, 1985) to the visual medium, in connection with assumptions of the alleged neutrality of the system designers. In this sense, this represents an instantiation of how visualisations can be involved in the process of 'ontological gerrymandering' (Woolgar & Pawluch, 1985; Arrington & Scweicker, 1992), namely making something problematic by making something else unproblematic. What the quotes above suggest is that, on the one hand, organisational members believe that visualisations are influential in shaping interpretation and understanding, while at the same time they regard as biasing the activity of being briefed by junior members of the organisation regarding the information content of the reports. Hence, ontological gerrymandering here operates by making problematic the reliance on an executive's judgment on their team's interpretation, while making unproblematic the visualising process and the interests of the designers. The tendency of problematizing the former more than the latter is connected to the appearance of objectivity provided by material artefacts and numerical pictures (Porter, 1995; Espeland & Stevens, 2008). Not only are data visualisations based on quantitative measures, but they have "stronger impact on the differences between different projects, [*and*] different areas that you're reporting" (board member 1). Accordingly, they show how this visual form of commensuration (see Espeland & Sauder, 2007) can – in a potentially misleading manner – magnify the perception of small quantitative differences.

5.3.4. Keeping reports ‘fit for purpose’ and the concern with minimalism

The organisational quest for identifying good designs does not seem to be based on aspirational ideals of all-encompassing representation and correspondence. Instead, it is grounded on a continuous effort of tweaking and tinkering with various templates to support decision-making in a context-specific manner, trying to ensure the reporting visualisations remain fit for purpose in connection with the delivery challenges of the programme at a given moment in time. Accordingly, to avoid some of the unintended consequences that visualisations may prompt (see Martinez & Cooper, 2017), the designs are themselves under scrutiny from within, and are assessed against their capacity for achieving what is believed to be their intended purpose:

There is always an element of constantly challenging internally, and saying, have we got that reporting dashboard right, is it still fit for purpose, and does it convey the information we want it to convey? (board member 1).

To ensure the designs can be rapidly adapted to fit the emerging situations that might arise in a specific delivery phase of the megaproject, the criteria according to which the templates are formulated are based on an activity of questioning the relevance, interest, and the facility of gathering and understanding a category of information:

In deciding the design, we always ask ourselves: How important is it? How interesting is it? How easy [*to design and understand*] is it? (controls manager 2).

These concerns are translated into the material design of the reports, which is also inspired by a minimalist approach to the realisation of the reporting products:

We always try to minimise the amount of stuff we generate to make sure people actually read it, and balance the inputs and the outputs trying to focus on what is important for the management at a given point in time (controls manager 1).

This attempt at achieving minimalism relates to both the quantity of the reports produced and the amount of data included in them. Minimalism is itself connected to the visual ethos of the organisation. A visual mode of presentation enables to condense information into more manageable reports:

You've got the technical dashboard page [*see figure 3*], that previously was a report in its own right, and that was probably 50 pages long. [*The performance summary of each project*], which is now a one-pager, it was covered in either pages and pages, or not at all, and was summarised only at the high level. So, on the one hand there was effort of trying to create clearer messages, but on the other hand was giving much richer information, eliminating the noise. [...] Before there was no context, so just by drawing a graph you see much more powerfully what the trend is over time. So, you're not reacting to little changes, or you're not missing the big picture. I tried to find the best medium, and the best format to suit the challenge, and think from the audience's perspective: What questions do they have, and what questions should they have? And to try and proactively answer it rather than give them a 5cm thick report and then see what questions they have and then give them more information to follow (senior manager 2).

This effort in achieving 'minimalism' translates into an attempt to reduce the amount of information reported and is coupled with a general concern with data quality, and emphasis on mechanisms to ensure a minimal level of manual intervention in data aggregation.

5.3.5. Using accounting data to prompt conversations

The concerns with minimalism above are considered instrumental by reporting designers in trying to maximise the usability of the reporting products. This usability is conceived as interrelated with the dialogical practices that surround the use of

reports. According to the controls managers, the following concerns connected to both the design and the practice of accounting information are essential preconditions for reporting to function:

It is fundamental to employ a given set of data to prompt conversation. If people do not trust the data, the conversations will revolve around the data as such and their validity, and that should not be the point of the conversation. The conversations should be about performance. [...] There are two preconditions: faith in information and collective understanding of what performance means at all levels of the programme (controls manager 1).

The lower the level of your data quality, the more scope you've got for gaming. Whereas at Crossrail we've got a single source of truth: Data is the data. Everyone accepts the data and focuses on what the data is saying, as opposed to whether the data's right or not (controls manager 2).

The quotes from the controls managers draw attention to two important points. The first highlights the importance of engaging in dialogical and conversational practices on the basis of the information provided (see Quattrone, 2015b). The quote from control manager 1 stresses the significance of going beyond the signifiatory and representational aspects (Thompson, 1998) to have productive conversations and reflections surrounding the negotiated controversies that emerge from accounting information (Mouritsen, 2010). The second one connects these concerns with the processes through which delivery information is gathered and assembled by data experts through highly automated processes. For this reason, managers are discouraged from questioning data accuracy and are instead stimulated to focus on their performance implications. This lack of questioning of the data appears to be deliberate and culturally driven. In fact, the belief in the quality of the information system in place is deemed sufficient to justify this attitude of focusing mainly on performance implications rather than information per se. In this sense, according to a senior manager:

Crossrail is now eight and a half years old, and we are in the situation where for the last four years, people have had a growing level of confidence in the quality of the data to the point where people don't question the quality of the data now. They are used to the fact that our processes and our systems are robust enough that they don't need to waste any time looking at the quality of information, they just need to focus their efforts on what the information is telling them. That is not the case in most organisations. If tomorrow I was transferred to [*infrastructure megaproject X*] I wouldn't have the same attitude towards data quality, you can be sure about that (senior manager 1).

As emerges from the evidence, reporting and its visual features are considered a driver of the success of a megaproject like Crossrail²⁶ – whose performance is a notable exception in the industry considering that it is on time and within the funding envelope (NAO, 2014; Marrs, 2016; Flyvbjerg, 2014). The visual design of the reporting products is treated seriously and guided by principles such as minimalism, consistency, and effort in establishing visual conventions that are shared and understood across the organisation. This is also corroborated by the narratives that can be identified in a series of Crossrail Learning Legacy documents and webinars (see Warren & Laws, 2016; Laws & English, 2016; Palczynski, 2016; Wood, 2016a, b).

As the evidence in this section has shown, the reporting ethos benefits from executive buy-in, which is often a precondition for establishing visual cultures and conventions in organisations (Henderson, 1995; Kostelnick & Hassett, 2003). In fact, for designs to come to fruition, influential people and groups within an organisation must 'jump on the bandwagon' (Fujimura, 1988). Culturally, this visual approach to reporting can be interpreted as a bandwagon that came into existence when a substantial number of people in the programme committed their resources to one approach to a problem (Fujimura, 1988) – in this case, treating reporting visually. This section sought to explore what constitutes the *ethos* of the reporting function in Crossrail. The next

²⁶ It is important to emphasise that nine years is an unusual length of time to have the benefit of management continuity for an infrastructure megaproject (see table 1). Conventional single programme procurement approximately ranges at two-three years periods, and the only equivalent examples are framework contracts with rolled up project portfolio to deliver over longer periods, which are typically small projects aggregated (see IPA, 2017a, b).

section investigates how Crossrail's reporting ethos had an impact on the design of dashboards.

5.4. Designing dashboards for megaprojects: The role of multimodal visualisations

The previous sections illustrated some of the main challenges of reporting in megaprojects and the ethos that supports the reporting function in Crossrail. To investigate how and according to which criteria visualisations are designed and practically constructed it is insightful to analyse several dashboards developed in Crossrail. The visual artefacts that are analysed are the Technical Dashboard, the Project Dashboard, and the Closeout Dashboard, which have all been designed bespoke by Programme Controls. The focus of this section lies on the layout characteristics of the dashboards in question, focusing primarily on how their templates organise the deployment of information content, and how they encode information necessary for project delivery. The approach taken is to focus primarily (but not exclusively) on designers, paying attention to the reason why they develop specific artefacts and to then explore how their efforts of pre-forming interaction unfold in use.

5.4.1. The need to go beyond tables and text

Figure 3 below is a dashboard produced by the technical department as a summary of technical activities to be included in the Board Report, containing a summary of indicators regarding the main operational concerns of the programme. This dashboard is used mostly at the lower level of the programme hierarchy and is employed by different departments. The most senior figures that use this dashboard are the executive committee members (e.g., Technical Director, Health & Safety Director, Operations Director) who, compared to non-executive directors (i.e., Board Members), tend to have more direct involvement with granular technical information.

Project Performance Summary - Technical

Report Owner	2) Safe Railway	3) Information Management	4) Quality	5) Testing & Commissioning	6) Sustainability & Consents	7) O&D
Period 10/2016/17	Key Performance Indicators	Information Management	Quality	Testing & Commissioning	Sustainability & Consents	O&D
Unbonded CEGBs	Infrastructure (FTI) Compliance %	Header/Ready	Work closing without ITP	Periods to Phase 2.1	Noise Performance	OAD PMS to contractors
# of 30 min. (or 60 min)	# FTI with no and/or violation in last 30 days	From C&I 2.1 (4th Preparation / 4th/5th/6th/7th)	# of Period	# Periods	Assessment (0-5)	#
Open IM Comments	Open Hazards	MCL Risk	Overdue NCR	T&C Readiness	Outstanding Consents	OAD PMS to contractors
#	#	MCL Risk	#	Readiness	Consents	#
Unbonded PMS	EM PI	Header/Ready	On Time Certification	T&C Readiness	Consents	OAD PMS to contractors
#	#	From C&I 2.1 (4th Preparation / 4th/5th/6th/7th)	%	Readiness	Consents	#
Open IM Comments	EM PI	MCL Risk	Car closed within use date*	T&C Readiness	Consents	OAD PMS to contractors
#	#	MCL Risk	%	Readiness	Consents	#
SECTOR A						
Contract 1	33%	0%	N/A	0.0	0	N/A
Contract 2	83%	0%	N/A	0.0	0	N/A
Contract 3	100%	0%	N/A	0.0	0	N/A
Contract 4	100%	0%	N/A	0.0	0	N/A
SECTOR B						
Contract 5	42%	1%	100%	0.0	0	N/A
Contract 6	32%	6%	100%	0.0	0	N/A
Contract 7	75%	0%	N/A	0.0	0	N/A
Contract 8	60%	9%	33%	0.0	0	N/A
Contract 9	55%	6%	N/A	0.0	0	N/A
Contract 10	50%	11%	N/A	0.0	0	N/A
Contract 11	83%	18%	100%	0.0	0	N/A
Contract 12	37%	0%	50%	0.0	0	N/A
Contract 13	74%	20%	100%	0.0	0	N/A
Contract 14	76%	1%	17%	0.0	0	N/A
Contract 15	79%	18%	87%	0.0	0	N/A
Contract 16	79%	5%	100%	0.0	0	N/A
Contract 17	43%	15%	N/A	0.0	0	N/A
Contract 18	42%	-	N/A	0.0	0	N/A
SECTOR C						
Contract 19	66%	0%	N/A	7.1	4	N/A
Contract 20	33%	20%	N/A	2.9	0	N/A
Contract 21	17%	44%	N/A	1.9	0	N/A
Contract 22	82%	0%	100%	0.0	4	N/A
Contract 23	92%	2%	N/A	0.0	0	N/A
Contract 24	37%	44%	N/A	0.0	1	N/A
Contract 25	1	-	N/A	0.0	2	N/A
OTHER						
Contract 26	0	-	N/A	0.0	1	N/A
Contract 27	0	-	N/A	0.0	2	N/A
TOTALS						
This Period	47	163	163	143	143	143
Last Period	43	120	120	137	137	137
Change	6%	28%	38%	4%	4%	4%

Figure 3. Technical dashboard (anonymised)

This dashboard provides summary level information of the central contracts in the programme, about: Design, safety, information management, quality, testing and commissioning, sustainability and consents, origin and destination. Since its intended audiences have a deep understanding of the data, the dashboard does not display striking design features. Features that stand out from the template are RAG (Red-Amber-Green) colour coding, performance trends indicated by coloured arrows (they indicate only fluctuations of $\pm 20\%$), and red boxes that highlight focus areas that require attention beyond colour coding and indicate parameters that registered unexpected fluctuations. These features are deemed to be sufficient to satisfy the needs of the technical department and the relevant executive directors. Just by glancing at it, the dashboard is not particularly informative and requires time, acquaintance, and specialist knowledge to be comprehended.

To be understood by people that are not as close to day-to-day operations as the technical department, a different design was developed because “numbers themselves are truly meaningful only to the people who define them and aggregate them” (external consultant 1). That is because:

It is those closest to the source of information that are in a better position to see the discrepancies or issues with the data being presented, versus those who are further removed from the data (controls engineer 1).

To facilitate the interpretation of those who are not as close to operational decision-making and delivery, figure 4 provides more relatable and contextualised information at project level.

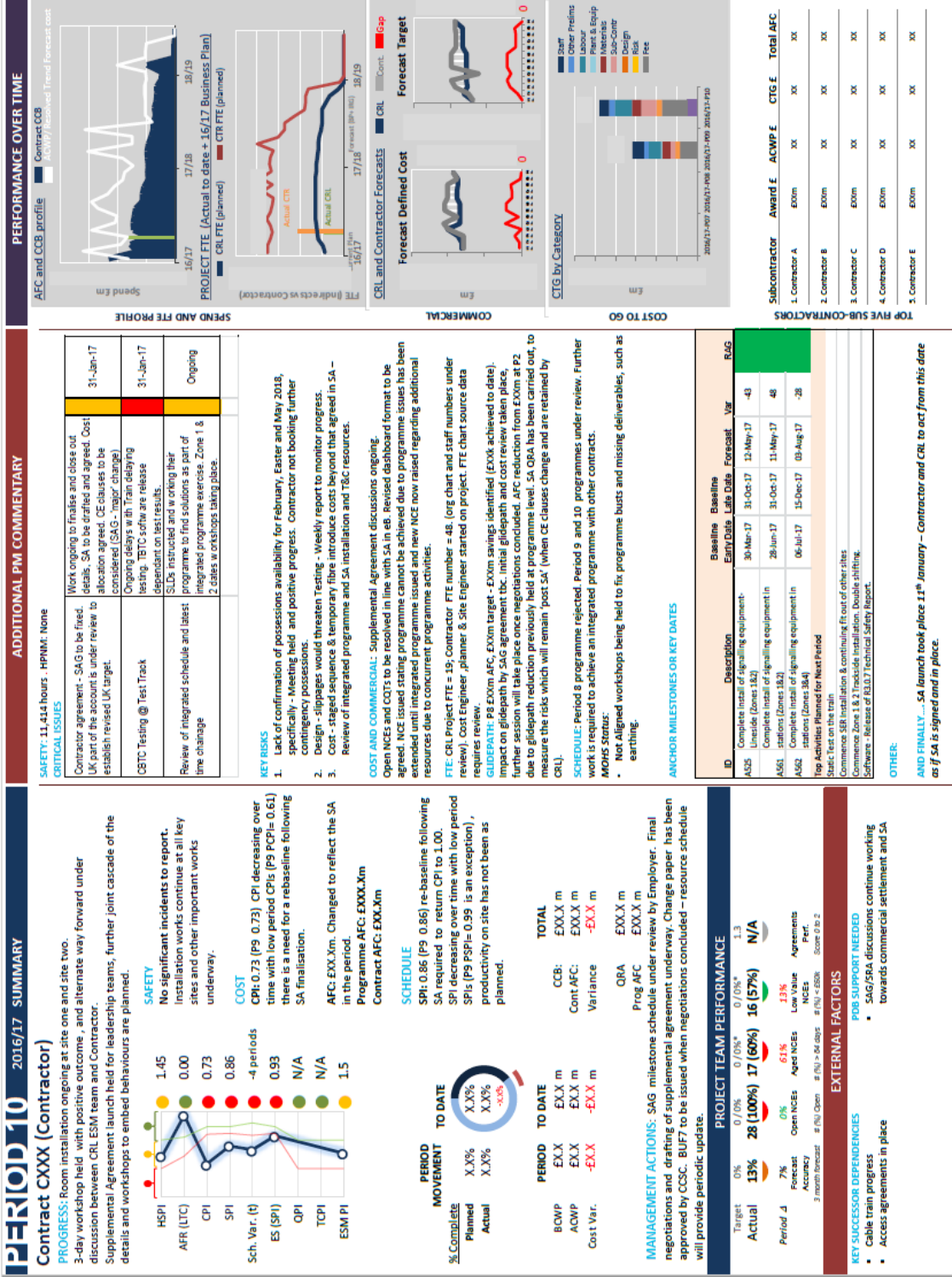


Figure 4. Project Dashboard (anonymised)

The move from data tables to dashboards was motivated by the following approach, which is in accordance with the ethos discussed earlier:

Once you have a report you have to ask yourself ‘what is the best way of presenting this?’, so that the people could comprehend what’s been provided, [...] particularly when they’re comparing a large number of contracts, at the same time, at any given point. If you simply left them as groups of tables, it’s too hard for people to comprehend and assimilate the information. You must be proactive and try to provide information in a way that makes it easier for people to interpret what’s being said (board member 2).

The dashboard (figure 4) contains information regarding progress, project team performance, external factors relevant for decision-making, commentary on risks and critical issues, milestones and key dates, and performance over time (spend, full-time equivalent, commercial, the cost to go, and ranking of subcontractors). Attention was put into the design of the template of the dashboard, which became:

The most important adaptive management tool that we designed to inform the conversations between project managers and programme executives (controls manager 1).

By adaptive management, the controls manager refers to an approach that aims to improve the organisation’s capacity to deal with uncertainty and the unexpected by learning from management outcomes and trying to iteratively design artefacts that can support decision-making in a context-specific manner.

5.4.2. Multimodality and balance in the design of dashboards that can pre-form conversations

According to one of the reporting designers, a core design criterion that was employed in the realisation of the dashboard was the idea of achieving a balance between the

different modes of presentation of information. A mode is “a socially shaped and culturally given semiotic resource for making meaning” (Kress, 2009, p. 79), and multimodality emphasises how communication occurs not just through writing (which is one mode) but also through speaking, gesture, gaze, and especially visual forms (Höllerer et al., 2017). In this sense, a multimodal balance of the elements to be included in the dashboard is achieved in the presence of the harmonious inclusion of the quantitative, qualitative, visual, and narrative components of the artefact. This is important considering how visual presentations of information can “facilitate the joining of not only multiple meanings, but multiple forms and formats of coded and uncoded, verbal, visual, mathematical, and tacit knowledge” (Henderson, 1995, p. 295).

Accordingly, a reporting designer contends that:

In the design of dashboards, we always try to balance ‘cold hard facts’, namely numbers, as well as commentary and visuals to support conversations about performance and delivery (controls engineer 1).

In turn, this criterion of balance is considered significant because of how the use of the dashboard can foster an overall appreciation of the interrelated and emerging complexities of a project:

In board meetings, my role is to make sure the discussion touches all the aspects of the dashboard, that no part is neglected. [...] Everyone has their priorities, and when we created this dashboard we were thinking about where the project is and what is relevant for today, beyond the biased priorities of the people involved (senior manager 1).

This visual artefact, thanks to its format and content, was designed with the intent of providing a synthesis of the project – for instance, in the case of figure 4, the dashboard visualises the construction of a new station – that would help to interrogate the relevant

delivery information and identify emerging issues (see Boland et al., 2008). The design of dashboards is intended to help managers to draw from their experience of similar projects to come to informed and context-dependent decisions. In this sense, dashboard design can serve as the gathering ground of a series of visual meta-indexical abilities (Henderson, 1995) such as the capacity to present different ways of knowing and the use of multiple systems of representation (i.e., the inclusion of verbal, narrative, mathematical, and technical elements that rely on different modes).

It is important to note that dashboards are designed to prompt conversations, questioning and the development of narratives on the basis of emergent matters of concern in the megaproject:

When the data look reasonably good, we let the project managers tell their own stories about what is going on. When the opposite happens, we use the dashboard to prompt conversation and interrogation, to get answers to question the data are suggesting us. Most of the time it is a prompt, some of the time it tells us exactly what we need. It depends on the individual project and its performance (senior manager 1).

The affordances of the dashboard aim to help managers to detect issues and anomalies, pre-forming conversations and interactions without unilaterally determining them (Hutchby, 2001). As the evidence above suggests, the project dashboard also contains an inventory of concerns that need to be addressed in the conversations about performance, yet it does not prescribe how to go about doing so (Quattrone, 2015b). In this sense, it preserves flexibility and ambiguity to leave room for professional judgment (Qu & Cooper, 2011). This highlights how visualisations can have the ability to represent knowledge through the flexibility of the combination of different modes of information (Henderson, 1995). In this sense, the designers believe that multimodality is an essential resource for the construction of dashboards. That is because, in the designers' view, drawing from the multimodal presentation of information can help users in the engagement with the inherent multiplicity of the megaproject and its always-unfolding ontology (Nocker, 2006). A multimodal

presentation of information is in fact believed to attract attention and engage users through the inclusion of different forms and patterns in the design of artefacts. Such engagement with the visualisation of distinct types of information that require different modes of presentation is in turn expected to help prevent standardised responses (Hedberg & Jönsson, 1978) in the engagement with indicators.

5.4.3. The importance of colour-coding conventions in dashboard design

Another core feature of the dashboards is the RAG (Red-Amber-Green) colour-coding, which can be seen in the diagram in the top left column, and in the commentary sections of the Project Dashboard and throughout the Technical Dashboard. Colour-coding is influential because:

The first thing you pick up is always the colours. [...] Text and numbers are there, but when you glance at something, it's the graphical input you get at first. [...] You see red and amber first, so you are drawn to it, you want to see why it is red. If you then go and read something in depth, you're going to read what's wrong first (controls engineer 2).

Colour-coding attracts the eye to inquire about the worst performing indicators in the visualisation, and this focus is obtained thanks to the intuitive and pre-attentive capacity of colours to attract attention (Cotgreave et al., 2017). The way that colours attract attention is connected to their symbolic meaning:

It's just the way we were brought up, is to perceive red as bad. In our culture, in the Western world, red is not good, and green is good, so you see it and you focus. And in China, it is actually the opposite. And sometimes that's the problem because things here are very visual, they might draw too much attention to them or the wrong kind of attention, so there might be an over-focus on things sometimes. As much as you try, or as much as you want to steer things maybe elsewhere, the focus of the board for those 15-20 minutes you're in there are drawn to these colourful errors which you don't want to maybe go into (controls engineer 3).

Dashboard designers are aware that colours are powerful in engaging users, but their capacity for attracting attention could backfire if they systematically over-emphasise some aspects at the expense of others. In this sense, in order not to over-emphasise the importance of specific colour-coded features, colour-coding and weighting require careful consideration and need to be deployed parsimoniously in the construction of visual artefacts:

If you have too much colour, you sort of numb it out. If everything is red, you go 'ok, it's all bad'. But if you only have one or two things [...] when you're trying to report this up to senior level, it draws their attention only to the items that really need attention to. If you have everything that is in red, that would say everything needs attention, because you haven't targeted certain things. And they don't have the time [...] so you need to focus on what you're asking for and use colours accordingly (controls engineer 2).

Accordingly, in the process of dashboard designs, colours, visualisations, quantitative information and commentary are orchestrated to balance each other out in the way in which they trigger attention and action. This is done to stimulate a harmonious consideration of the dashboard as a tool to foster conversations and help to make sense of complex situations. As the designers argue, a balanced mobilisation of colours can do more than just attract attention, and instead stimulate the detection and classification of emerging issues in megaproject by flagging matters of concerns. This is achieved by the open-ended nature of the RAG coding technique:

Colour makes you look at the high-risk areas first. [...] But the Red-Amber-Green thing tells you very little. You can use it for anything. I mean, it's all about how you use it, and to makes sure it helps people to see things that you already spotted putting the dashboard together. Then it's also up to them to understand what that means for them (controls engineer 3).

According to the evidence presented, RAG is a standardised code that creates a lexicon to maintain familiarity and consistency of meaning among different visual artefacts.

By means of its simplicity, RAG can expand a given visual lexicon so that new codes can be incorporated and interpreted inventively in innovative design features. In this sense, the power of the RAG visual convention resides in what Cook (2004) calls ‘symbolic poverty’. The cognitive economy of a visual code characterised by symbolic poverty can be interpreted as a virtue as it offers opportunities for interactions between communities of users. The incompleteness in the use standardised codes – such as RAG – can be argued to reside in the symbolic poverty, namely what gives them value “as a way of specifying the series of social actions and interaction of which any performance consists” (Cook, 2004, p. 87).

This section sought to explore some of the criteria for the practical constructions of dashboards in Crossrail, focusing on how the design of reports is influence by the designers’ reliance on multimodality. The next section investigates how visualisations are tweaked by the designers to support engagement with different delivery phases.

5.5. Adapting visualisations to the always unfolding nature of megaproject delivery

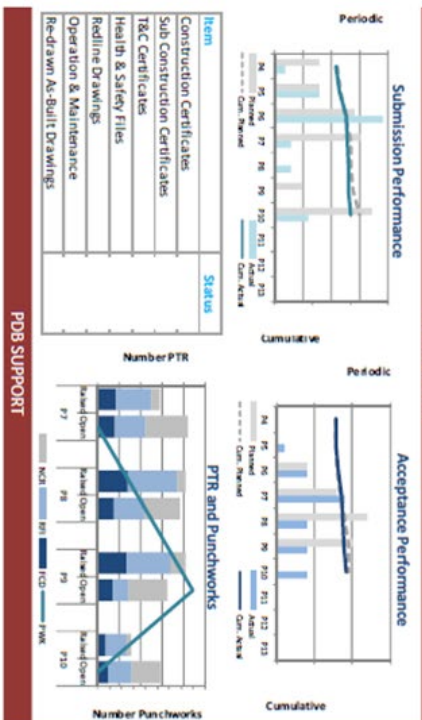
Ensuring that visual artefacts are fit for purpose and can facilitate delivery throughout the different phases of the programme is a central concern of reporting designers, personnel and control managers. They are strive to identify room for improvement in the design of the reports to ensure they can support engagement with the challenges of the programme as a temporary and ever-changing project structure (Molloy & Wittington, 2006). To investigate an instance of how such an adaptation process occurs it is insightful to explore the reasons the led to the development of the Closeout Dashboard (figure 5).

PERIOD 10 2016/17 **CLOSE OUT DASHBOARD**

Contract CXXX (Contractor) **0 days LTC** **0 Minor**
0 hours LTC **Injury**

Employers Completion	Progress	Due Date	Comments
CD1 ECR Notification	COMPLETED	Mar-13	CD1 Construction Manager has notified the MFLS/DCI of compliance with the review of the works and associated documentation for Employer's Completion Process. Completion date has changed to 29th February 2017 for the New Form to be issued.
CD1 Health and Safety	Mar-13	Contractor to provide evidence of health and safety risk assessment for the site. Risk Register to be updated to include the new form. Risk Register to be provided to the Employer by 29th Feb 2017. CD1 to provide evidence of the YAM, WCHA and CHSMA and to provide on time the review of analysis and evidence of activities.	
CD1 Technical Compliance	Mar-13	Contractor to provide evidence of compliance with the requirements to provide evidence for the duration of the YAM, WCHA and CHSMA and to provide on time the review of analysis and evidence of activities.	
CD1 Planning & Heritage	Mar-13	Contractor to provide evidence of compliance with the requirements to provide evidence for the duration of the YAM, WCHA and CHSMA and to provide on time the review of analysis and evidence of activities.	
CD1 Environment	Mar-13	Contractor to provide evidence of compliance with the requirements to provide evidence for the duration of the YAM, WCHA and CHSMA and to provide on time the review of analysis and evidence of activities.	
CD1 US&C	Mar-13	Majority of commitments to be completed and compliance planning updated. CD1 to be updated and evidence provided.	
CD1 Estate Management	Mar-13	Contractor to provide evidence of compliance with the requirements to provide evidence for the duration of the YAM, WCHA and CHSMA and to provide on time the review of analysis and evidence of activities.	
CD1 Rail interfaces	Mar-13	Contractor to provide evidence of compliance with the requirements to provide evidence for the duration of the YAM, WCHA and CHSMA and to provide on time the review of analysis and evidence of activities.	
CD1 System wide	Mar-13	Contractor to provide evidence of compliance with the requirements to provide evidence for the duration of the YAM, WCHA and CHSMA and to provide on time the review of analysis and evidence of activities.	
CD1 Technical Information	Mar-13	Contractor to provide evidence of compliance with the requirements to provide evidence for the duration of the YAM, WCHA and CHSMA and to provide on time the review of analysis and evidence of activities.	
CD1 Third Party Agreements	Mar-13	Contractor to provide evidence of compliance with the requirements to provide evidence for the duration of the YAM, WCHA and CHSMA and to provide on time the review of analysis and evidence of activities.	
CD10 Completion	Mar-13	Contractor to provide evidence of compliance with the requirements to provide evidence for the duration of the YAM, WCHA and CHSMA and to provide on time the review of analysis and evidence of activities.	
WCCD/KCCC	Mar-13	Contractor to provide evidence of compliance with the requirements to provide evidence for the duration of the YAM, WCHA and CHSMA and to provide on time the review of analysis and evidence of activities.	

CERTIFICATION



• Care and Custody contracts details under review.

PDB SUPPORT

ADDITIONAL PM COMMENTARY

ECR CRITICAL:

Description	Action/Update	Severity	Date Recd
1) Gate wrap up	Gate wrap up plan 12/12/16, 20 of 44 deliveries outstanding to be done out by 24/02/2017	High	Jan 2017
2) PFO and Design Oversight	Overseeing documentation to closeout	Medium	Ongoing
3) Agreement of IM and Property Boundaries	Complete property and IM boundaries to be resolved between multiple stakeholders	Medium	Ongoing

CRITICAL ISSUES

Description	Action/Update	Severity	Date Recd
1) Design Completion	Outstanding design items to be produced to support current construction milestones and prevent prolongation of works	High	Ongoing
2) Visual design and programme impact	Small section of additional cut of rail being revised by discovery of historic well design solution to be developed	Medium	Ongoing
3) Long Lead Items	As remaining PCC design deliverables are released there are long lead items identified which will extend the contract beyond the 31/03/17, incl. Gates, Security grilles, riser flooring and replacement doors. Mitigation is being explored but many items have multiple order from other CR contracts	Medium	Ongoing

PROGRESS:

- Completed Urban Realm Grasswork signs.
- The Landscape & Urban Realm works have progressed well in the period with paving, fencing, top soiling and planting progressing to the northern area along New Barrow Road.
- RLP defence wall - case and wets RC construction completed and brickwork coating commenced.
- Phase 2 contractor paving, programming and furniture installation ongoing to urban landscape. Work re-started, remaining works to finish.
- Backlog installation around the EIP and the demobilisation of the ground remediation set-up signified the completion of major excavation works on the project.
- Complete VTC ductwork, cabling & equipment installation, commence Stage 2.1 Training
- Progress EIP drainage and External Works
- Progress DUA M&E installation works Phase 2, and DUA station forecourt External Works
- Complete external lighting (including external lighting) & greenway trees

MANAGEMENT ACTIONS:

Focus on successful completion of the remaining activities including physical works, documentation and Employer's Completion Process.

OUTSTANDING CONSTRUCTION ACTIVITIES:

Activity	Target Date	Forecast Date
Activity 1	30-Aug-16	17-Feb-17
Activity 2	16-Dec-16	16-Dec-16
Activity 3	16-Dec-16	16-Dec-16
Activity 4	16-Dec-16	15-Jan-17
Activity 5	28-Feb-17	15-Mar-17

ISM CLOSEOUT

- ISM decommissioned, final RTIS monitoring end.

COMMERCIAL CLOSEOUT

- COO1:**
- F10 Cum. CH = 0.90 / Commercially Adjusted Cum. CH = 0.96
 - Programme AEC = £000.0m (includes £000.0m O&M)
 - ACPV = £000.0m - Certified = £000.0m (£0m of Security)
- SCHEDULE**
- F10 % Physical Completed = 90.7% vs Planned = 92.5%
 - F10 Cum. SPI = 0.98
- CONTRACT ADMIN**
- No CES have been implemented / related in the period due to CA resource being focused on assisting the employer with SA
 - Statement agreement approved by COC on the 13 December 2016
 - CCA Cost does not pick up £0.0m of allowances. Hence showing the AEC (£000.0m prvm vs £000m CCA)

Account Overview

Account Overview	MS	CEL
Current Target	£000m	£000m
CEI accepted	£00m	£00m
CEI under review	£00m	£00m
CEI rejected	£00m	£00m
CEI to be submitted	£00m	£00m
Total Forecast Target	£000m	£000m
Cost to Date	£000m	£000m
Cost to Go	£000m	£000m
Total AEC Forecast	£000m	£000m
Pay/Inch Share	£000m	-£00m PAIN
Fiscal Account	£000m	£000m

CLOSE OUT ACTIVITIES

Description	Submission Date
Close out of all Current Open NICE	09-Mar-17
Demobilised Costs and CAES	15-Feb-17
Complete Review of 80% Subcontractor Accounts (1)	29-Mar-17
Complete Review of all Remaining Sub-contractor Accounts	TBA
Provisional Agreement of Final Accounts (1)	31-Jan-17
Replacement Warranty (1)	31-Jan-17
Care and Custody for AEC to be provided VTC account for redress of health insurance work(1)	31-Jan-17
Assurance Documentation - Final Gate wrap up to close out remaining actions	24-Jan-17

(1) Identified in Contract Commercial Close out Plan.

DEMobilISATION GRAPH

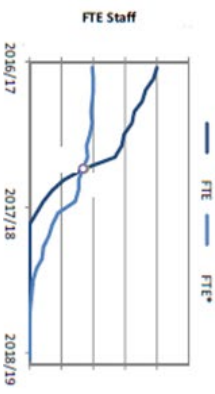


Figure 5. Closeout dashboard (anonymised)

Controls managers, project managers and those responsible for oversight and assurance (e.g., the government's Project Representative Team) in Crossrail felt the Project Dashboard (figure 4) was not particularly useful in dealing with projects heading towards completion. That is because project management challenges in the closing out phase are rather specific:

Completion has a nasty tendency of having a long tail. The focus becomes different [...] and completism is quite an art. People that are not completist enjoy carrying things on to a level of accuracy that is unnecessary. Completists are the ones you need at the endgame, where you know you can secure signoffs and is not necessary to go on to silly extents (project representative 1).

The closeout dashboard was explicitly designed to contribute to addressing these issues. In this dashboard, the diagram in the top-left corner of figure 4 is replaced by a colour-coded table that emphasises what is to yet to be finalised, and the inclusion of graphs on demobilisation and certification. One of the critical factors in visual configuration of figure 5 was the selection of the information that had to be excluded from the Project Dashboard, while at the same time increasing the visibility of specific parameters. Most of the KPIs of the project dashboard are no longer present in figure 5 and other graphs (such as the demobilisation graph and the outstanding construction activities) are more visually prominent to emphasise their importance in achieving timely completion.

5.5.1. Magnifying incompleteness to drive behaviour

This closeout dashboard is introduced when a project (e.g., a station) is at approximately 80% completion. At that point finalising the project is more important than tracking performance and that is why the use of KPIs is regarded as potentially misleading. Focusing on what is yet to be completed appears to be paramount, for behavioural and motivational as well as technical reasons. Because of the specificity of issues such a driving people to achieve sign-offs, it appears crucial to present information in different visual formats:

When the project is running at full speed ahead, it has momentum, so when there's a problem, it's being actively tackled and resolved. [...] When it gets to the closeout stage, there's no full-on activity. So, you've lost your momentum. [...] It slows down because you want them to sign something saying it's 100% done, no one will. The challenge is to drive them to want to accept that 'we're done, and everything is there'. You have to provide information in different forms. [...] The attitude changes and you need to have managerial skills for both [*phases*], and visualisations help you to drive leadership (controls engineer 2).

In this sense, the dashboard aims to attract attention and engage users by ways of its emphasis on what is not yet finalised. That is of great importance because, in project delivery, closing out activities can take much longer than expected, even if the amount of work yet to be done in absolute terms might appear trivial. According to a controls engineer:

When you get to the end and it's at 95%, it looks good, but that 5% is still a big gap, and because you're de-staffing and demobilising, attitudes change and people are often less motivated. [...] What you find is that 5% that you think would be so easy to closeout takes much longer. Because we need to close down all these activities [...], we need, like a zoom, or enlargement of that aspect. Although it's not really the 5%, it's always the whole thing, and you need to force people to understand the all thing is at stake if you want to push them (controls engineer 2).

To avoid losing momentum, the closeout dashboard magnifies what is incomplete and increases the visibility of apparently small figures in order to induce people to act on the basis of what they perceive as requiring intervention. In this sense, increasing the visibility of what is still incomplete appears to be critical in magnifying the perception of the activities that require attention and intervention.

5.5.2. The elusiveness of aesthetic criteria

In a program like Crossrail, the design and implementation of different dashboards is crucial and having a supporting culture that is sensitive to these issues is a precondition for their successful application. That is because the design of a dashboard and its implementation require a commitment of time, resources and efforts, and several rounds of tweaking, testing, and adaptation²⁷. In fact, to finalise the closeout dashboard, “there were 15-20 different versions we went through in about two months until we felt it was good enough” (controls engineer 2) until figure 5 was approved by the Board as it was deemed based the strictly necessary information for the closing out phase.

However, when asked about how they reached consensus around the approval of the final design, the reporting designers failed to express convincingly why this specific iteration was selected amongst the several other drafts that were produced. The only tangible criteria they were able to identify was a practical concern with ensuring that repetition was kept to a minimum in the layout and that the core progress information would immediately stand out to the informed user. As controls engineer 3 argues:

I’m not sure about why they approved this one. For sure one of the issues is avoiding repeating stuff that is already somewhere else. Also, representing the right type of information with right kind of visual is not obvious, like knowing when to use a table, a graph or whatever. Before, we used to have pie charts for some indicators, but that didn’t quite work. [...] I think we reached a point in which we felt it just worked. It felt analytical enough and simple enough. [...] But it’s not like ticking boxes.

²⁷ Part of the drive behind Crossrail’s effort in developing visual designs for different reporting products is connected with its Learning Legacy Programme, the objective of which is “to share knowledge and insight, through means such as case studies and technical papers providing lessons and recommendations to help others. Documents and templates that have been used successfully on the Crossrail programme can be ‘pinched with pride’ by other projects, and datasets will be made available that can inform future research projects. The Learning Legacy also showcases the experts behind the delivery of the Crossrail programme” (Crossrail Learning Legacy, 2018).

As it appears from the quote, the reporting designers failed to point out what stopped their design process and subsequent rounds of tinkering and adaptation. This consideration points to the tacit nature (Polanyi, 2009) of aesthetic knowledge in the design of material artefacts (Ewenstein & Whyte 2007) and the resistance to the formalisation of aesthetic design criteria. In this sense, the experiential element of feeling and acquired sensitivity in understanding the aesthetic experience that artefacts may deliver is linked to deliberate choices. In turn, these choices of design features to achieve an outcome that conveys aesthetic properties that can be recognised by the interactor (Stigliani & Ravasi, 2018) appears to relate more profoundly to a variety of situational judgements and cultivated sensitivity than to an activity of ‘ticking boxes’ on the basis of a fully conceptualised model of the design activity.

5.5.3. The population of the dashboard as an opportunity for reflection and self-reporting

Having dashboards that are purposefully tailored to supporting specific phases of project delivery is considered paramount for Programme Controls. However, dashboards as reporting tools are not only significant once they are finalised but creating them and entering data has significant implications (see Qu & Cooper, 2011; Bloomfield & Vurdubakis, 1994). The activity of populating the dashboard template (after it has been designed) is another dimension of the influence of such artefacts on the management of the megaproject. The population of the dashboard is an activity that occurs throughout the reporting cycle and, before approval, concerns mostly individual project managers on site. This activity seems to have substantial implications for the project managers in question and, as the evidence suggests, it enables the visual template to function as a tool for self-reporting (see Quattrone, 2004, 2009). According to one of the participants:

Every time you are updating [*the closeout dashboard*], you are also reporting yourself, you are running your objective, and you’re realising what you need to do, and what you are going to do. [...] You are updating this every period, so you are providing a summary of what you’ve done that month. If you’re

writing your summary and you realise ‘well I haven’t done anything here, and this needs to be changed’, you say ‘what did I do for the last four weeks, what have I achieved in my work in the last four weeks’? Because, ultimately, the whole of Crossrail is here to deliver something, so if you have not delivered something in that one month, it is a bad month. It is like you are providing yourself with some feedback on what have and what I haven’t done, and at the same time, when you have done this, and you find much change, you feel good about it. When you do this closeout dashboard, and you are writing the progress in, and you see what needs to be done, especially if it needs completion, you say ‘ok, maybe next period I want to put my efforts in here’ (controls engineer 2).

In this sense, the closeout dashboard may be implicated in the personal scrutiny of individual performance that, in turn, is believed to help to create a sense of momentum in the closing out phase, stimulating the focus on subsequent activities ahead of the next reporting exercise. Similarly, another controls engineer argues that populating the dashboard is a significant activity that helps people ‘keeping on top of their work’. In her specific case, the controls engineer is commenting on the Quality Dashboard which, among other features, contains a performance ranking of the contractors involved, in a league table format (a format is which is known to induce powerful reactive behaviours –Espeland & Sauder, 2007):

Filling the dashboard is something that requires a lot of attention and this is one of the things that makes people not slack [...] they can’t just let four weeks go and then don’t do anything, so it’s a constant incentive, people having to keep on top of what they should be keeping on top of. People don’t want to be at the bottom [*of the performance ranking*]. [...] If people see themselves at the bottom, like ‘what we’re doing this month’, and it’s a drive to improve themselves and talk to other people about what they are doing, get information shared, lessons learned, find out what these guys at the top are doing and try to be like them, so it helps to try to keep on top of your work, and always have quality improvements (controls engineer 3).

The evidence above illustrates the significance of individual-level engagement with the artefact, and the learning process implied by the activity of filling the dashboard. In this sense, dashboard production can function as an individual learning opportunity that is connected to the temporal aspect of the reporting cycle.

5.5.4. Visualisations at the centre of routines

The temporal aspect of the reporting cycle is profoundly connected to the establishment of a productive routine in construction of these visual artefacts. Accordingly, a senior manager contends that routinized process of dashboard production is of utmost importance:

As a project manager is important that you stop, take stock of where you are at with the job, summarise all aspects and know where you are at then, you can start again. Plan, do check, act. And you keep going around that circle. Getting the project to produce dashboards is a very a good way of keeping that discipline to stop on a regular basis, summarise where they are at, think about it, and start again. It gives a rhythm, the reporting rhythm that keeps us from getting lost in the details or getting distracted (senior manager 1).

The practical construction of various reports emerges as important mechanisms to keep controls managers 'located in the present'. In this sense, the creation of a reporting rhythm as a productive routine is not only seen as a precondition for the timely creation of the reports but also is considered necessary to ensure that reporting itself becomes a systematic learning opportunity. According to a manager in Programme Controls:

Rhythm in creating the reports and dashboards is very important. It enforces the reporting discipline, I always stress the importance of maintaining the cadence of the reports, the programme reporting rhythm. It's very important we hold a rhythm because the reports are coordinated with the governance structure. The information which we generate in our reports goes to feed meetings, at which either sense is made, a conversation is had, and decisions are made. And principally we generate information to support the conversation between the project managers and the programme executives. [...] Actually, doing the dashboard helps you understand and learning a lot of important things about the projects, and doing that repeatedly every four weeks helps you keeping track of everything that's happening. [...] It's all about establishing a productive routine (controls manager 1).

The piece of evidence above is insightful in illustrating the importance of the routinized activity of populating dashboards in the reporting cycle. In this sense, the activity of dashboard production shows the centrality of visual artefacts among the agencies involved in routinized performances that support coordination among organisational functions. Although these visual artefacts are not the routine, they highlight how routine-following is distributed and shaped by the material agencies of the reporting products and cycle (D'Adderio, 2011). Dashboard population hence functions as an obligatory passage point (D'Adderio, 2008) that enables multiple representations and performance to co-evolve. In so doing, the routine of dashboard production plays an important role as a learning opportunity. The learning opportunity, which partly occurs through self-reporting in dashboard creation, appears to be an enabling factor in facilitating understanding and reflection on critical issues project delivery (see Quattrone, 2004, 2017). This process, coupled with the activity of scrutiny towards the reporting tools and visual artefacts employed in each phase, contributes to the internal activity of reflection towards the reporting products discussed earlier and is used as a feedback loop to ensure that the dashboards are fit for purpose.

Despite the value attributed to dashboards and their construction by the participants, there is also an element of resistance and scepticism towards the value of keeping in place such a highly governed reporting routine. According to an executive director, reporting takes too much time and effort:

I think the [*Programme Board Report*] is a good example of this problem, do you really need a two-day meeting every month, every period to actually do that? The programme director, who has got more experience than a lot of us put together, believes very strongly that if you don't have that structure, you won't get people to work. I don't disagree with him on that, but the amount of work that goes into producing the documentation for the [*Board Report*] is phenomenal, and it's unrelenting and is that the best way to get things done. If you go out on site at the moment, people will tell you they have got so much work to do, not just reporting, but office-based, they find it difficult and not all of them necessarily see the value. And [*the Programme Director*] is very clear, without this level of reporting, without this routine, you will not get things

done, and I think there is lots of evidence that shows that, but it is very time-consuming. This approach enforces a routine, it delivers the milestones, it gets people producing stuff, but sometimes is just the amount of stuff, the quality of the stuff that you have got to do, it is time-consuming and sometimes I think we should have a more open conversation about how we feel about it (executive director 2).

The evidence from the executive director emphasises one crucial point, namely the delicate issue of achieving a balance between the value of a tight reporting routine that is believed to be critical in ensuring managers are on top of their work, and the amount of work required to produce the outcome products of the reporting function. In this specific instance, the Programme Director seems unwilling to compromise on a routine that may seem cumbersome to certain executive directors. In an informal interview, the Programme Director expressed his belief that – although the reporting routine might at times be indeed excessive especially given the world-class level of Crossrail’s performance – its benefits outweigh the costs in that in complex megaprojects achieving reliability and adaptability to emerging circumstances is, in his view, more important than short-term efficiency.

5.6. Bridging the elusive gap between reporting and action: On how the visualisation of consequences helps driving behaviour

Crossrail management’s reliance on visualisations in programme delivery does not only relate to the domains of reflection, scrutiny and facilitating the development of a mental synthesis, but expands to the effort in designing ‘behavioural tools’ that are considered to be capable of driving specific collective behaviours of groups in the organisation. A central concern of Programme Controls is the realisation of visualisations that help organising group participation (see Whyte *et al.*, 2016; Comi & Whyte, 2017), in a way that supports a proactive attitude towards reporting information. According to one of the board members, the visualisations designed in the program – at the highest level of generality – have fundamentally two purposes:

The purpose of these visualisations is to communicate messages and to drive behaviour. We want to ensure that people understand what's going on in their project. Do they understand the impact of the work that happened, the events that happened in the last four weeks? Do they understand the impact that that is having overall? And, by seeing it all in the context of one piece of paper for the programme, do they understand what impact do they have on the ability for Crossrail to complete successfully? [...] [*The visualisations*] are designed to force people to think about things, and that is driving behaviour (board member 2).

Visualisations are designed with the goal of transmitting meaning, stimulating understanding and, based on that, driving behaviours. According to the board member, these two purposes appear not to be necessarily connected to ideas of representation or correspondence, instead they primarily seem to have to make sense and help people making sense of the situations they face (Weick, 2004, p. 41). There is one peculiar feature that characterises the design of visualisations in Programme Controls, namely the way in which designers draw from their interpretation of concepts borrowed from behavioural sciences in their activity of designing artefacts to shape managerial decisions. The mobilisation of these notions informs understanding of how designers interpret the elusive link between reporting and action through the medium of visualisations. This section explores the criteria according to which the performance assurance scoring framework for tier 1 contractors was designed, contextualising it with the criteria that informed the design choices.

To explore why and how the visualisations contained in the performance assurance framework are regarded as 'behavioural tools' that affect the relationship between reporting and action, it is important to provide the background of how the performance assurance exercise was designed and coordinated in Crossrail. It was in fact articulated as follows:

Crossrail's approach to performance measurement was based on six core areas aligned to corporate objectives, using traditional quantitative based KPIs but supplemented with qualitative based assessments of the supply chain's maturity to provide a richer picture of supply-chain performance. This enabled the targeted sharing of knowledge and innovation to support supply-chain

capability improvement and drove a 54% increase in the supply chain's performance levels over a 3 year period, and resulted in 14 out of 17 assessed contracts operating over-and-above the requirements of the contract (Crossrail, 2016, Performance Assurance, unpublished internal document).

Six rounds of performance assurance reviews, every six months, were undertaken to assess contractors' performance until the program reached 75% completion. The scoring system in figure 6 is obtained connecting qualitative inputs with quantitative outputs. The assurance model spanned across six core areas aligned with corporate objectives, namely: Social sustainability, commercial, target zero (i.e., the safety culture), environment, quality, community relations (Wood, 2016a, b). The qualitative inputs, or 'lead indicators', refer to the approach to delivery, quality of system and processes, competency, policies, procedures, and management arrangements. The quantitative outputs, or 'lag indicators', refer to quantitative KPIs. Across these aspects, performance is measured on a scale from 0-3, where: 0 equals non-compliant with processes, procedures, and contract; 1 indicates basic performance compliance; 2 indicates value added compliance; 3 indicates world-class performance (Wood, 2016a, b). Input maturity scores were calculated upon a collaborative review process, procedures and management arrangements with each of the Tier 1 contractors during onsite meetings.

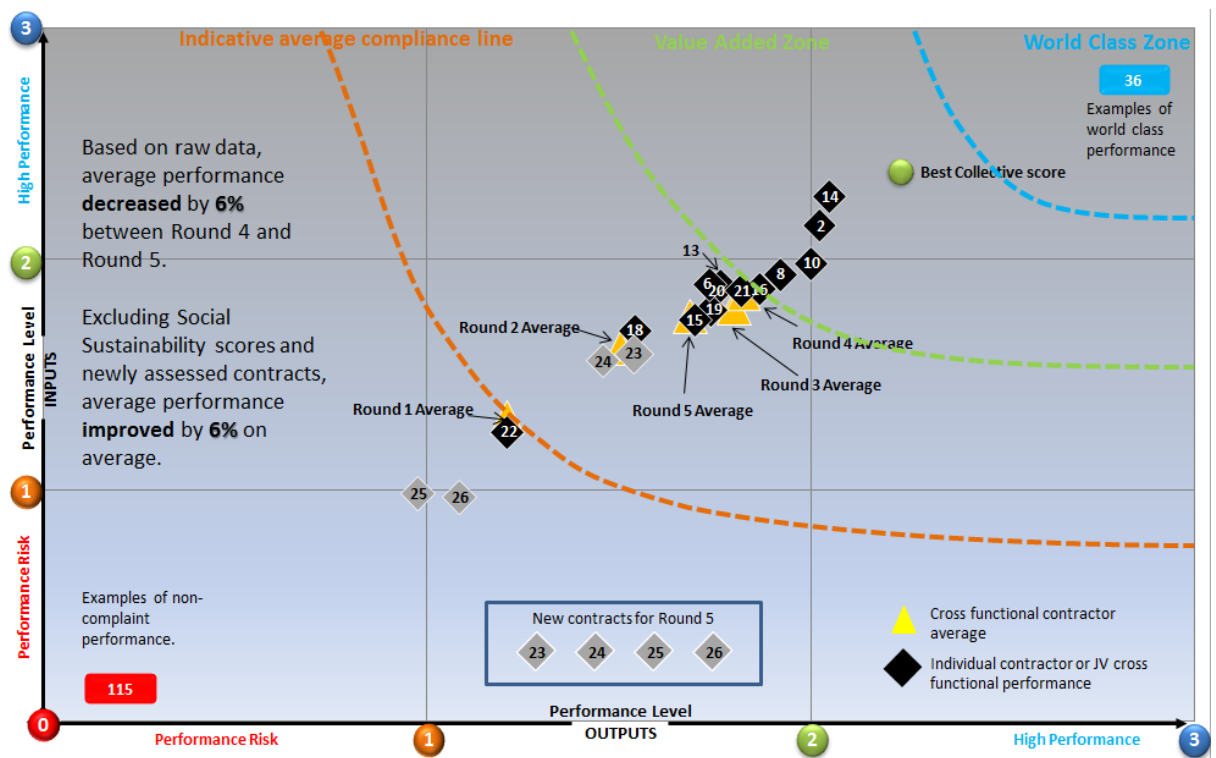
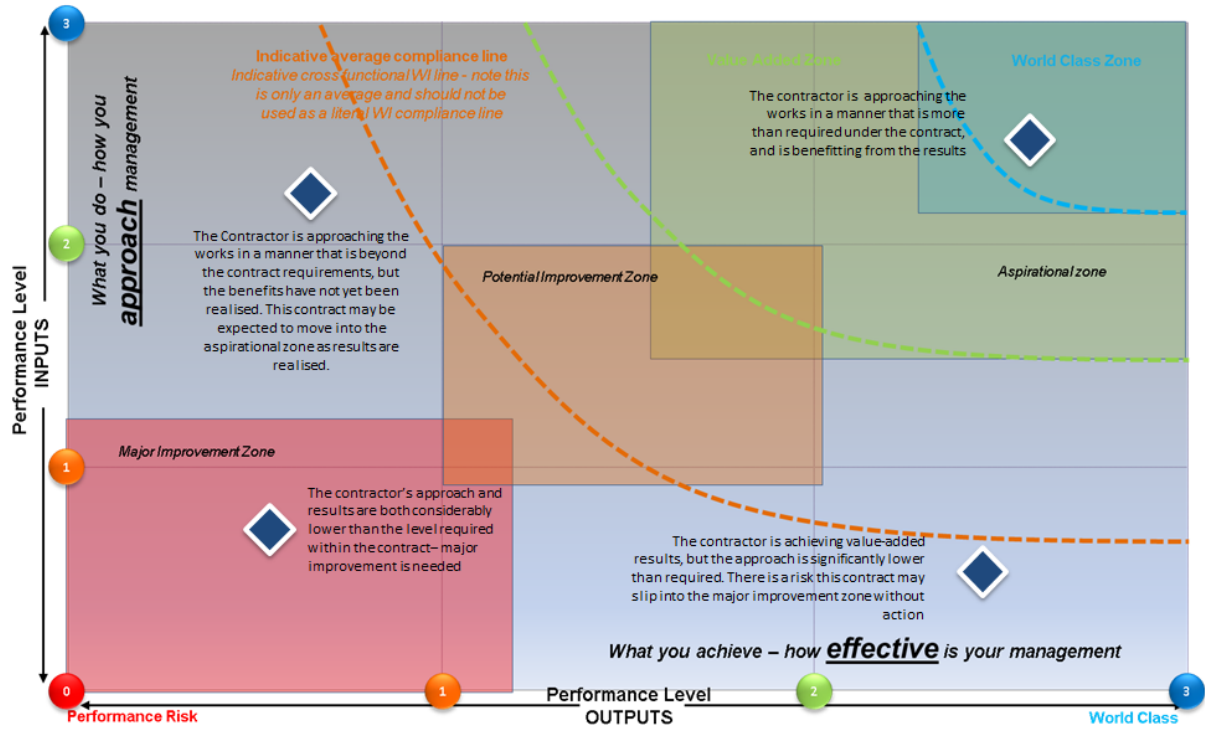


Figure 6. Performance assurance scoring framework visualisations (anonymised)

The ways in which information is plotted in the graph is colour coded, designed to highlight zones of overlap, trajectories of performance improvement, and aims to make it easy to grasp at a glance performance trends. Information related to single contractor's performance and cross-functional contractor average and composite scores are plotted with indicators that are shaped and coloured differently. The presence of dotted lines separating the four different performance areas facilitates the identification of outliers. This visualisation was produced to be discussed with the contractors' community in the assurance reviews. These meetings involved senior managers and executives from Crossrail and the CEOs of the contractor companies. The description of the performance assurance exercise undertaken so far was aimed at setting the scene to discuss how the visualisations above were designed and how they unfolded in use.

5.6.1. The design of 'behavioural tools'

The application of behavioural principles to simulate proactivity and drive behaviour is evident in the design of the processes and visual-material artefacts that characterise Crossrail's performance assurance scoring framework. Initially, in the assurance meetings, the contractors' labels were anonymised as in figure 6, and only each contractor knew their relative position in the graph. During the first round of performance assurance review, the CEOs of the tier 1 contractor companies and senior Crossrail executives were in the same room, and the Crossrail team used the graphs to illustrate the result of the assurance exercise. The graph was used to guide the conversation and illustrate the contractor's performance anonymously. Senior manager 4, who was present at the meeting and involved in the assurance process recalls what follows:

No one back then knew who the other numbers were. But, after we presented the review, [CEO A], the chief executive and founder of [Company A], looked at his number and saw he was the lowest performing contractor on the graph, and stood up in front of the other executives and said: 'Hello, I am [CEO A], I own and run [Company A], my number is [n], and as you can see on the visual

I am the lowest performing contractor. In 6 months' time, we are going to come back and give a look at round [*n+1*] and I am not going to be the worst performer'. [...] That drove a set of behaviours straight away among the contracting community because none of them wanted to be the lowest performing, it is human nature, no one wants to be recognised as a poor performer. [...] [*CEO A*] in that instance was exceptionally brave to step up, recognise where his company was at, and they are one of the top performing contractors now (senior manager 4).

This anecdote is well known in the organisation and was mentioned by most of the participants as a crucial event in the history of performance assurance reviews in Crossrail. The action of CEO A – albeit motivated from a competitive personal drive – is believed to have triggered a set of virtuous behaviours in the contractors' community and is regarded by the participants as a crucial event that induced transparency and trust in the assurance process. Most of the participants see a direct link between this action of CEO A and the removal of anonymity from the graph in the following assurance reviews, thereby making individual performance public among the contractor's community. Various participants believe that the reaction of CEO A was partly triggered by how the visualisation in question was designed, in combination with its situation of use during the assurance scoring exercise. Senior manager 1, who was present that day and that was also personally involved in the design of the scoring framework, commenting on the same event claims that:

Because of how we visualised the data, all the contractors agreed to take the anonymity out [...]. The way in which we visualised that certainly drove part of the competitive behaviour and the improvement. This is because visuals can be used to trigger and drive behaviours quite precisely [...]. When you use data, you must be careful and accurate, and you have to be able to provide examples as to why you are either good or average or bad, but as long as you can do that, trust the power of data and visuals because it gives people nowhere to escape. They just can't deny it [...] the contractors could not deny it. And depending on how you visualise data, it is a hugely powerful way in which to change people's behaviour, especially if you are dealing with CEOs and senior people, who are very experienced, but also extremely competitive, but because of that [*they are also*] to an extent predictable, especially in front of their peers, and you can leverage on that using visualizations strategically (senior manager 1).

Similarly, according to an executive director, visualisations can help leveraging on the competitive drive of senior executives:

There's no doubt that exploiting that competitive element is quite useful. Senior people are naturally competitive people. That is how they got to the top. And so, actually using that degree of competitive exposure, showing them visually that they're not as good as they think they are, or they might be better. So, the ones who are good are giving the praise, the benefit can be tangible for them (executive director 2).

As the evidence suggests, the design of the visualisation in figure 6 was not coincidental, but was also achieved thinking about its situation of use, namely as the focal point of a meeting with CEOs and key representatives of the contractor community.

5.6.2. The visualisation of consequences

The mechanisms by which these visualisations are designed with the idea of driving behaviours are grounded on a precise interpretation of the implications that notions borrowed from behavioural sciences can have if applied to the design of organisational artefacts. This section explores the interpretation that the participants offered of the theories that, in their opinion, lie behind the performance assurance exercise and design of visualisations in Crossrail more broadly. According to a senior manager, drawing from behavioural science is of great importance in programme management:

The performance assurance framework is a very specific example of using visual data to drive behaviours. Behavioural science is a topic all by itself. [...] To design these visuals you have to understand how the human brain works. If you want to change someone's behaviour, you are better off doing that by applying consequences as opposed to what, in behavioural terms, is called planting an antecedent. For example, how do you change a car driver's habits in terms of speed that they drive at? A driver in a car enters a 30 mile an hour zone. They see the sign, the sign is the antecedent. [...] A lot of people don't drive at 30 miles an hour. [...] However, when they see a flash of light, and a speed camera has gone off, instantaneously the vast majority of people slow

down because the camera gave them a consequence. They immediately associated the flash with a negative consequence. Or in some cases, they perceive that as an immediate punishment, and they change their behaviour. And that's true across the board, generally speaking, 80% of your behaviour is influenced by the consequences you receive, and only 20% is influenced by the antecedents that preceded the behaviour (senior manager 1).

The attention to behavioural aspects in the construction of the visualisations for the performance assurance framework appears from the quotes by senior manager 1, who designs visual artefacts in close collaboration with controls engineer 1, who is a chartered experimental psychologist who holds a management accounting certification. The quote from senior manager 1 above illustrates how any form of design is always, implicitly or explicitly, grounded on a theory about the influence of the material on behaviour (Gaver, 1991; Sengres & Gaver, 2006). According to senior manager 1, the principles and criteria according to which visual artefacts are designed can leverage on powerful behavioural notions – such as the concept of consequences versus antecedents (Miltenberger, 2008) and leverage on face-saving mechanisms (Keil *et al.*, 2007) – to foster the influence of visualisations. This perspective – which, as such, may be considered reductionist – is nonetheless effective in illustrating how the design features of Crossrail visualisations are often not serendipitous but based on a precise conceptual articulation of how material artefacts can shape behaviour and influence interpretative processes. The reflections of managers, controls engineers and designers on the theoretical underpinnings of how the affordances of visual artefacts can pre-form interactions and practices of future use is not only relevant in the 'design mode' but also in the 'use mode' (Orlikowski, 1992).

The situation of use of use of figure 6 is in fact characterised by competitive pressure among the CEOs of different contractor companies in the room, and the graph deliberately highlights the importance of increasing the visibility of consequences:

In the example about [*CEO A*] and the performance assurance framework, he stood up in that room and said 'I am at the bottom of this list, but next time I am going to improve my behaviour'. He received a consequence – not just an

antecedent – he saw that graph and perceived his name being at the bottom of the list as a consequence, and he decided then to do something about it. There are many ways in which you can try to shape behaviour, and there are different types of consequences that you can apply. Understanding how to influence behaviour is a science, it is in a category of science all on its own, and good project managers understand what tools to use in certain situations to elicit changes in the behaviours within the individuals in their team (senior manager 1).

In this sense, employing carefully designed visualisations to drive behaviour by increasing the visibility of consequences (as opposed to antecedents) is a widely practised strategy in Programme Controls. Magnifying consequences relying on visual artefacts can also be used as a governing tool for a senior manager to exert an extent of control over more senior figures, such as board members, executive directors, and CEOs of contractor companies. In this sense, a senior manager maintains the following:

Depending on how you visualise data, it is a hugely powerful way in which to change people's behaviour. And that is for contractors, project managers, for sector managers, and for executive board managers. Every year the executive team are benchmarked, they look at core KPIs, how much compensation bonus they get is largely determined by the performance across a range of KPIs, and this, in slightly different ways, is true also for the contractors and their obligations. For this financial year, we did a model to project where at six months the likely outcome was a 12 month, we were effectively telling the CEO and other executives: 'If don't do something about this and that you are not going to get much money this year'. Showing and visualising the consequences of their actions is a hugely powerful way of driving people's behaviour (senior manager 4).

Although the point of senior manager 4 could be interpreted as a rational approach to economic incentives, the focus here does not lie on the incentive as such, but on how the visualisation shapes the perception of a situation and induces ways of thinking about the future (Comi & Whyte, 2018). As it appears from the evidence above, visualising information compellingly is not only a means of pre-forming interaction (Stark & Paravel, 2008; Kaplan, 2011), but can also subliminally create visibilities that enable managers to challenge and influence the behaviour of senior executives and

their perceptions of situations. As will be shown by the following quotes, these design criteria are more than a rational approach to incentives because such visualisations prompt associations and reasons for appropriation that exceed their representational value and as well as the assumptions of utility maximising behaviour. In fact, the design of visual artefacts can prompt a variety of consequences, which can cause different reactive behaviours:

There are four types of consequences. You can have what people perceive as positive reinforcement, negative reinforcement, punishment, and then you can have what in behavioural science they call extinction. If I like a piece of work that you've done, and I say 'thank you', and give you a pat on the back, that immediately is positive reinforcement. You did a behaviour and you received something positive as a result of doing the behaviour. Positive reinforcement has the effect of making people want to do that same behaviour again. [...] Negative reinforcement is the threat of something happening that doesn't ever happen. [...] If it is just simply left as a threat, then it has little influence. Behaviours, generally, don't change as a result of being threatened. The third category, a punishment, has the effect of immediately stopping a behaviour from occurring. So [...] you only ever apply a punishment when you want a behaviour to stop, and you have to be very careful because sometimes, you have to understand that 'it is in the eye of the beholder' to assess as whether or not your actions are a punishment or a reinforcement of sorts. [...] Extinction is continuously ignoring someone when a behaviour happens until it stops. [...] I always think of these four consequences when I suggest changes to our reports. [...] You never know how [*these changes*] will work because people are unpredictable, but making them think about what's going to happen is very useful and it is largely down to the power of data, and the way in which you can communicate it and visualise it to drive people (senior manager 1).

The understanding of behavioural principles that characterises designers in Programme Controls informs their deployment of specific design features in reporting visualisations that have the intent of mitigating or emphasising specific behavioural tendencies. Although the four consequences discussed by senior manager 1 are all not equally applicable to data visualisations, they are indicative of their possibilities for deployment as factors that can influence behaviour. However, as argued by senior manager 1, these notions are not necessarily mobilised in reductionist capacity with the intent of giving an illusion of predictability. Rather, their represent an analytical template to reflect on how interactors may think about the future and about what such

a possible future may mean for them. Accordingly, thinking about the effects of future consequences entails a reflection on the possible reasons for appropriation of measures and indicators that interactors may have (see Comi & Whyte, 2017; Preston, 1986). In this sense, the quote illustrates the potential of design – as a praxis based on the deliberate construction of artefacts and processes in a community of practice – in evaluating the features that are deemed to be influential in pre-forming interaction.

Building on these insights, a senior manager in Programme Controls summarises compellingly the objectives of reporting design in Crossrail:

Reports should prompt things and should allow better understanding. Particularly if your reporting is consistent, month on month, versus other projects in deliberately consistent format. So, you can pair like with like, and really mentally understand that the trends are your ultimate acquisition. Then you can build on the understanding to drive what's important, thinking carefully what I need to worry about, what can I do differently, what actions do I need to take for me or my team. That's the difficult bit, it's that link between reporting and action, and it's all very well focusing on reporting. Visuals can nudge behaviour, but what happens in between is murky. But, the reporting is only there for a reason, which is to make better decisions and give confidence. The purpose of this was, one, give confidence, two, greater control, and three, risk reduction, they were the three primary objectives of the reporting. And you need to remember that, by which I mean some people only focus on the confidence bit, which is just the audit trail and it is all great, don't worry. Other people only focus on the control, other just on risk. But you cannot predict things, so it is also important that reporting make you reflect on situations (senior manager 4).

As emerges from the quote above, the 'link between reporting and action' is problematic. In Crossrail, both designers and users of reporting products appear to attribute to visualisations an almost idealised status, and regard visualisations themselves as the most effective medium to make reporting actionable. The evidence presented so far shows how both designers and users believe in this ethos of the organisation – what senior manager 2 encapsulated effectively in the sentence: “the ethos of ‘if in doubt, draw a graph’”. The consolidations of forms of visibility into

material visualisations is a process that, by definition, crystallises certain aspects at the expense of others, and its specific patterns of exclusion and inclusion are by definition non-neutral. Once visualisations are designed – be those graphs, tables or dashboards – they “redefine space, wiping clean all irrelevant details” (Myers 1988, p. 239) and structure claims and the objects of the illustration and the visibility they create (Busco & Quattrone, 2015; Cooper *et al.*, 2017). As the evidence suggests, information quality and accuracy are preconditions for effective reporting yet, when it comes to visualisations, these concerns do not seem to be the most relevant ones. One could argue that “graphs have an effect even when the data in them are subjective, qualitative, or imaginary” (Myers 1988, p. 248), and what the evidence suggests is that the form of the mode of presentation is a fundamental factor influencing interpretation, understanding, communication and action.

5.6.3. Unintended consequences of visual practices and the value of imperfection

The link between reporting and action, which emerged as particularly challenging to identify, is believed to be facilitated by the visual ethos of the organisation. However, when asked to expand on the reasons and the aspects that make it difficult to act upon the basis of reporting information, two Executive Directors identified some important constraints in the use of visualisations:

[Despite the progressive cuts in the length of the reports] I think there is still too much reporting, and the reports are often too detailed and long. [...] This is quite a governed project, there’s lots of reports that are produced. It’s quite tricky to further cut the reporting when you’ve got a board that is used to a visual board report, and suddenly it does not get it in the same way, they go ‘where’s our report?’. And you go ‘well we’re not going to produce as much because you do not need it’. And there’s quite a debate about that. [...] Cutting the reporting is for me necessary to maximise the use of the reports we already have. I think we need to get smarter at producing better but shorter reports. A lot of the time it is the discussion around the report that’s more important than the report itself (executive director 2).

The length of the reports and the amount of information they contain can have negative consequences both about the use of the reports itself – and the conversation it prompts –, and about the inhibiting effects in relation to the path-dependency associated with the expectations of the Board. Similarly, when asked to expand on the reasons that prevent reporting from becoming more actionable, another Executive Director pointed to the importance having a more visible element of personal judgement to support the performance analysis in the reports.

My personal opinion is that we do too much reporting. I think we provide too much data and not enough analysis. When I say analysis, I don't mean technical analysis, what I mean is getting the opinion of experienced people about progress. There is a big emphasis on data and facts and analysis of data. There's not very much attention paid to people's experience over many years and their intuition, and their judgement about what is happening. I would reduce the amount, I don't think our board can assimilate all the information in that board report. [...] I would have more emphasis on the personal judgement of the senior people in the organisation, because just looking at data, no matter how smart the programme controls people are with their visualisations, will only give you another view of the data (executive director 1).

The issue pointed out in the piece of evidence above, which links to the rationale of having a visual report as means to capitalise on the experience of the senior decision-maker discussed in section 5.3, points to a concern that was not perceived as problematic by most of the other participants. The issue is the link between visualisations and judgement – and, more abstractly, the problem of ontological gerrymander in relation to the design activity. Visualisations have largely been discussed in this case as thinking tools that can shape and support decision-making (see Stigliani & Ravasi, 2012; Jarzabkowski & Kaplan, 2015). Notably, many aspects of resistance were discussed, yet none of them seemed to imply the risk that visualisations may share with numbers a major risk: That of closing conversations (Porter, 1995; Quattrone, 2017). The evidence below seem to suggest that visualisations that are too 'perfect' may convey what Porter (1995) calls 'mechanical objectivity', which could potentially go against the reasons they were designed for in the first place:

Look at this [*pointing at the diagram in the project dashboard*]. This gives you some information at a glance, but there's no judgement in this. It's all factual. And when the project manager comes and reports, at the programme delivery board [...] what the project manager does is he or she just starts talking about what's on here. Whereas actually what you ideally want is to throw that away, literally, put it to one side and say to the contractor, say to the project manager 'right, you're an experienced person, you've got 25 years' experience in the construction industry, tell me how you think it's going on. Give me your judgement'. I think the Programme Controls people are brilliant. I've never seen reporting done better. But it's so good that it discourages you to let the project managers just present a report, you want to know what their judgement is. And above the project managers you've got the delivery directors, what is their judgement? Then you should gather the judgement supported by the facts, rather than just go through the facts. There's a risk the reports become so good that they prevent judgement and that sometimes paralyses things rather than facilitating them (executive director 1).

Several insights can be gained from the quote by the executive director. He emphasises how, for visualisations to be genuinely involved in the process of routinizing the exercise of questioning and scrutiny (see Revellino & Mouritsen, 2015; Quattrone, 2017), they should include by design an element of judgement. The inclusion of judgement seems to be necessarily connected with the narrative aspect (Garud et al., 2008) of data visualisations and their practice. The exercise of judgement, according to the evidence, might be hindered if the visualisations themselves are – or are portrayed and believed to be – too 'perfect', as they may convey an element of facticity which can discourage the exercise of reflection and questioning. In this sense, the evidence indirectly suggests that an extent of deliberate ambiguity and incompleteness in the designs could break assumptions of mechanical objectivity, thereby making impossible to infer an answer mechanically from a set of pre-specified indicators. If this was to happen, professional judgement would be enabled to emerge more strongly: "If people are enabled to play a substantial role in determining the meaning of systems, this implies that they will be actively engaged in process of understanding both the system and its situation of use" (Sengers & Gaver, 2006, p. 101).

This section explored how designers deploy specific features in the creation of visualisations such as the performance assurance scoring framework with the precise intent of bridging the gap between reporting and action. In so doing, they rely significantly on the visualisation of consequences (as opposed to antecedents), drawing inspiration for the field of behavioural science. The next section illustrates how a specific KPIs visualisation, the ‘worm diagram’, supports the delivery of the megaproject and contributes to the development of visual conventions in the programme.

5.7. Worm diagrams: The roles of visual patterns in supporting megaproject delivery

The previous sections discussed the importance of dashboards design in supporting the delivery of the megaproject and the influence of visualisations in informing the link between knowledge and action. Additionally, they showed the criteria according to which dashboards are designed to engage with different delivery phases, detailing how factors such the reliance on multimodality and the importance of the activity of populating the dashboard can function as learning opportunities. This section focuses on the roles of discernible and memorable visual patterns as design characteristics of visualisations. These visual patterns are interpreted as being able to facilitate the emergence of visual affordances that can help interactors forming a sense of the ‘bigger picture’ (see Boland et al., 2008; Kornberger & Clegg, 2011; Comi & Whyte, 2017) in programme delivery, while supporting the activity diagnosis of emergent issues. To explore these issues, this section focuses on the design features of the ‘worm diagram’, a particularly important visualisation designed and used in Crossrail.

5.7.1. The ‘worm diagram’

The worm diagram (figure 7) is deployed in the top-left of the Project Dashboard to further increase its visibility. It is conceived as a visualisation that enables interactors

to make confident judgements based on quick observations of numbers – what Pollock & Campagnolo (2015) call *subitizing*. The diagram is meant to enable interactors to subitize key performance information before dwelling on the details of the report. The worm diagram appears in a visually consistent format in most of the Crossrail reporting products, namely: Project dashboards, sector director reports, board reports, and in informal management control tools and programme dashboards. This diagram is a performance management visualisation that was originally designed and presented by the former Head of Performance in the 2015 Crossrail Leadership Conference as an informal sketch of the entire programme’s performance for a keynote speech. The visual design was then perfected by the former Head of Performance in collaboration with the previous Finance Director²⁸. After several rounds of tweaking and adaptation, the worm diagram was progressively included in several reports, contributing to the development and consolidation of visual conventions (Kostlenick & Hassett, 2003) and optical consistency among organisational artefacts (Latour, 1986).

²⁸ The position of Finance Director in the megaproject entails also a sit in the Crossrail Board of Directors. As board members, both the former Finance Director and the current (board member 1) are responsible – among other duties in their remit – from the Programme Controls department. In this sense, the figure of the Finance Director not only is profoundly connected to Programme Controls, but is also part of the reason why the controls function appears to be so impactful in shaping decision-making in the organization. Additionally, it is important to point out that Programme Controls does not report to the Programme Director, hence there is no line management opportunity to impose the Programme Director’s view of the programme’s health and maturity in reporting terms.

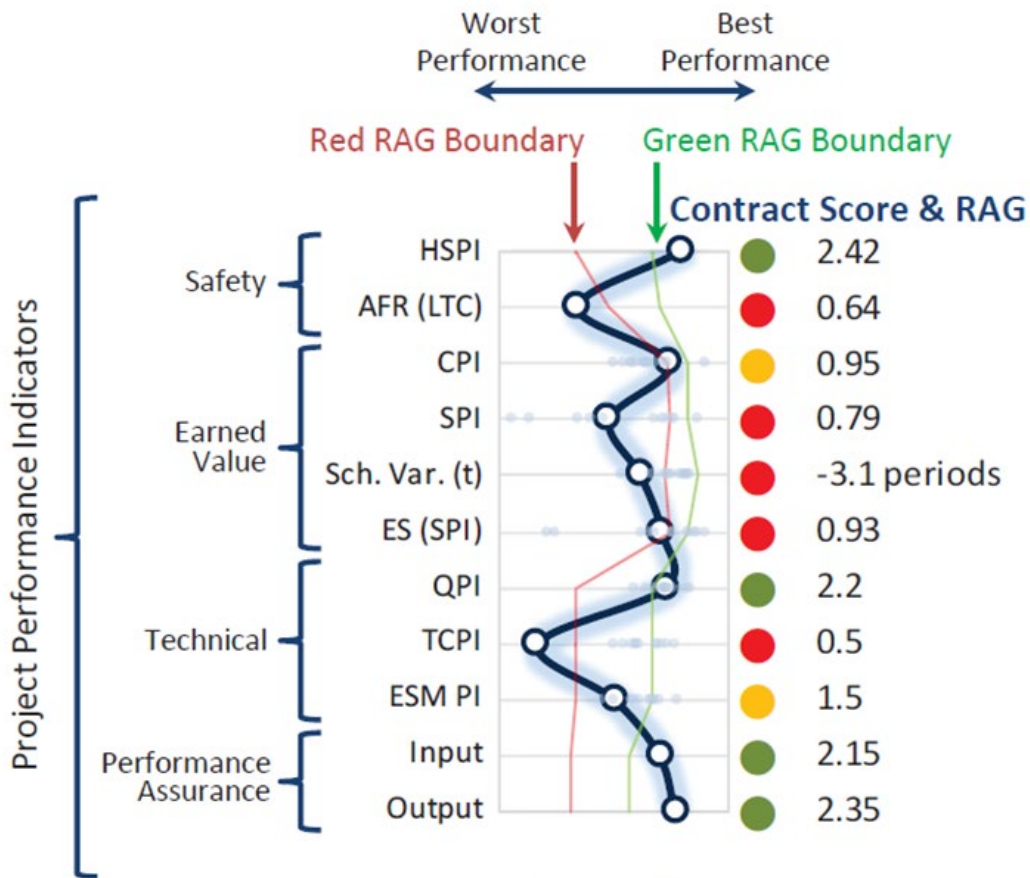


Figure 7. The ‘worm diagram’ with explanation

Figure 7 has specific features that, through their repeated use and appearance in different reporting products, enable specific affordances to emerge in interaction. Firstly, the performance indicators on the left side of the diagram relate to the four central concerns of the megaproject (i.e., safety, earned value, technical indicators, and performance assurance). The KPIs are organised in a vertical but conceptually non-hierarchical manner, and all carry equal weight in the generation of the visual pattern. This feature aims to ensure that all the dimensions are considered and are present when acting based on the visual, trying to move beyond strict concerns with value for money. In this sense, the visual relationality of the worm diagram aims to foster a holistic consideration of the project in question and moves beyond the emphasis on the bottom line that characterise more standard visual presentations, such as data tables. The RAG colour-coding in the dots on the right, in association with its quantitative measures, is included to stimulate a focus on anomalies and – given the tendency of colours to

trigger attention – it aims to prompt a concern with the worst performing indicators and high-risk areas (Cotgreave *et al.*, 2017). The two RAG boundary lines, namely the visual cues of the range of acceptance of a given KPI score, guide the interpretation of the position of the dots with the meaning of each colour-coded element. This feature intends to ensure that the weighting criteria are understandable. These design features are deployed with the intent of fostering a comprehensive consideration of the visual pattern based on KPIs and the relational and interconnected nature of its features.

The design and translation of such principles into operational artefacts is deliberate and consistent in the program, as there is a shared belief that:

It is important to translate the core objectives into the design of performance measurement tools that we use. This way people always keep them in mind and negotiate with them even if they are not normally inclined to do so (project representative 2).

Hence, the visualisation of an inclusive set of value dimensions in visual artefacts is not coincidental, but based on the idea that visualisations can increase the visibility of indicators that may otherwise not be prioritised to a sufficient extent (see Cardinaels & van Veen-Dirks, 2010). Broadening the set of indicators which is visualised in an artefact, bridging divides and creating shared reference points (Jarzabkowski & Kaplan, 2015) appears to be an attempt at mitigating or preventing standardised responses (Hedberg & Jönsson, 1978) that have specific cultural determinants. In the case of figure 7, the pattern of visual relations is regarded by the participants as the most influential feature of the diagram. However, despite being rich in content, this visualisation is not extraordinarily compelling in isolation. According to the person who designed the worm diagrams:

I'm a great believer in trying to keep things simple, and this may not appear straightforward. There's a lot of data there. But once you understood what this is showing you, and remembering that each of these is a 200,300-million-pound project, therefore you must take the time to understand it. Once you do

understand it, it's actually really simple to assess, but remembering that not everyone is financially literate. [...] Some people like words, some people like numbers, so this was always a mix of words and numbers. My experience of successfully implementing the worm diagram here is that once you acclimatise people to it, then it's easy to understand going forward. Just by glancing at the diagrams, your mind subconsciously processes them and sees the trends (senior manager 2).

5.7.2. The visual relationality of performance patterns: The 'programme dashboard'

To facilitate comparisons and associations among different projects and give a sense of the interconnectedness and heterogeneity of the program, all the diagrams were combined into one single poster. The poster (figure 8) illustrates the differences in the visual patterns of the worm diagrams and was designed with the intent of developing a comprehensive yet simplified overview of the megaproject. The poster is employed as an instrument to question project managers in an informal capacity, and as a tool to guide conversations among the senior management in governance meetings.

The objective of the poster in figure 8 is to create a visualisation that helps managers to go beyond the structural limitations of the project dashboard and create an overall picture of the entire programme. This artefact leverages on the visual relationality of the patterns of the worm diagrams acquire if put side by side, thanks to the comparability and memorability of their forms and shapes. According to a senior manager in Programme Controls:

When you see an individual project dashboard it is very easy to get a feel for where the project is at, but it is not necessarily easy to get a feel for where the program as a whole is at, until you have read every single project dashboard and you somehow try to remember them. The ability to put all of the project information on one single piece of paper creates a dashboard that is the closest thing we have to an actual Crossrail programme dashboard. [...] You are reading the same information [*as in the single project dashboards*], but here you very quickly can compare one project to another and get a sense of the bigger picture (senior manager 1).



Figure 8. Photo of the office of the Director of Programme Controls. Poster in the background (anonymised)

This visualisation is almost exclusively used in its printout form, and the reason for this relates to the specific advantages of the materiality of the artefact over a digital format. It is in fact believed that not only the format but also the material configuration of the artefact and its situation of use can have profound implications:

The poster has presence. Because of its size, and because it's on the wall, it's not just like an electronic file stored somewhere on the computer. Printing it out makes it ten times more powerful and useful (controls manager 1).

Similarly, according to a senior manager, the visualisation of information in a material artefact designed to facilitate the activity of creating mental connections and associations can enable the perception of emergent properties (Barry & Miesiek, 2010; Ware, 2012):

There is no other way to do this apart from a poster and its physicality. The first time we printed it out and put it up in the office, it was the first time we could visually see the performance consistently, ordered by type and progress and look for the differences and see the anomalies and oddities. This was the first time we had seen the profile. We had the data all the time, but nobody put it in a graph, and we could not really see it in a data table. The poster showed us many anomalies, and immediately we went on questioning the managers about it. [...] This is always first and foremost a learning exercise and only secondly a reporting exercise (senior manager 2).

Looking at the poster, it is intuitive to spot trends and get an overview of the complexity of this multi-billion pounds megaproject. That appears because the pattern of the lines is relatively easy to understand relationally and is visualised memorably and consistently across the artefact. Additionally, most of its components (e.g., worm diagrams and performance over time) are reported in a manner that is optically consistent with their presentation in other reports (i.e., project dashboards) and relies on similar visual conventions and presentation features.

According to a senior manager, relying on visualisations to provide a synthetic overview of the programme helps to mitigate certain behavioural issues that might arise in organisations associated with human numerical information processing.

I think that [*the poster*] allows you to see the volume, and then it allows you to understand the bigger picture. So, on any project where you have monthly reporting, if you are not careful, if you don't have the context, the history, you are only looking at what's happening that month. That's the most important, but you might be missing the bigger picture. So, a particular metric might go off 5%. But if the metric is doing that, you just tend to fixate on that one month. So, how do you strip out the noise? And I think visualisation is such a critical way of doing that. [...] And the poster does that pretty well. My experience is that people aren't very good with numbers, and my readings on behavioural economics tell me the same. They think they are, and I include myself, but I'm sure at times I'm not, all my biases affect what I remember and are often self-serving. In my position, I have to curate what I tell the board. The temptation's there, isn't it? To only give the good news, or only talk to them the things you want to talk about. Not that I do that, obviously, but you have the power to provide all the numbers, which numbers do you show, and how do you show them. That's why visualisation is one key tool, it's not the only answer, but it's a critical answer (senior manager 4).

The deployment of specific visual features in the poster, such as the visualisation of the worm diagrams put side by side, was aimed at achieving a visual relationality that facilitates the creation of associations that would help interactors going beyond the specific concerns of each project. The aim of creating visual association among patterns of performance indicators intends to prevent over-reliance on individual-level numerical information processing. This is an issue that may affect even experienced professionals (Garcia-Retamero et al., 2015), due to overconfidence and optimism bias (Kramer, 2016). In this sense, visuals are involved in “trying to prevent optimism bias and other systematic behavioural errors to travel to our reporting” (project representative 1) and, in the case of the programme dashboard, this was achieved by a visual articulation that aims to facilitate the perception of the complexity and emergent properties of the programme.

5.7.3. Designing the beautiful picture

The design criteria according to which the poster was developed were not only based on accuracy and functional specifications, as its aesthetic features were regarded as a fundamental precondition for successful interactions practices of future use. In fact:

We did this design for visual purposes, what fitted best on the poster, effectively. Creating a dashboard is one thing, creating a poster is as much about presentation of information as it is about the quality of information. There is no point in having a 99% accurate set of information that looks terrible, because no one is ever going to look at it. Part of the whole art of program controls is making information visually capturing to the eye, so that people are drawn to it, and want to ask questions (senior manager 2).

The evidence illustrates how aesthetic considerations inform the design of reporting products. The creation of a ‘beautiful picture’ (Espeland & Stevens, 2008; Pollock & D’Adderio, 2012) that attracts attention is considered an important enabling factor in making people wanting to enquire and engage with the visual artefacts in question. Figure 9 below illustrates how the former Head of Performance conceived of the creation of the worm diagrams – one of the core features of the poster – as the outcome of trade-offs between what he calls ‘artistry’ – namely the aesthetic domain – and the concern with achieving ‘business value’ – or the domain of functional ideals.

Several insights can be gained from figure 9. What appears from the visualisation combined with the quote from senior manager 2 is that aesthetics (or ‘artistry’) plays a role that is far from being merely accessory to the function of the visual artefact in question. In fact, saying that the current performance visualisations are an outcome of functional and aesthetic considerations, implies that aesthetic concerns are not an epiphenomenon but are deliberately sought after because of the effects they are expected to have in interaction. This issue raises the question of what the status of aesthetic attributes in organisational artefacts is, and how they can be designed to have these properties.

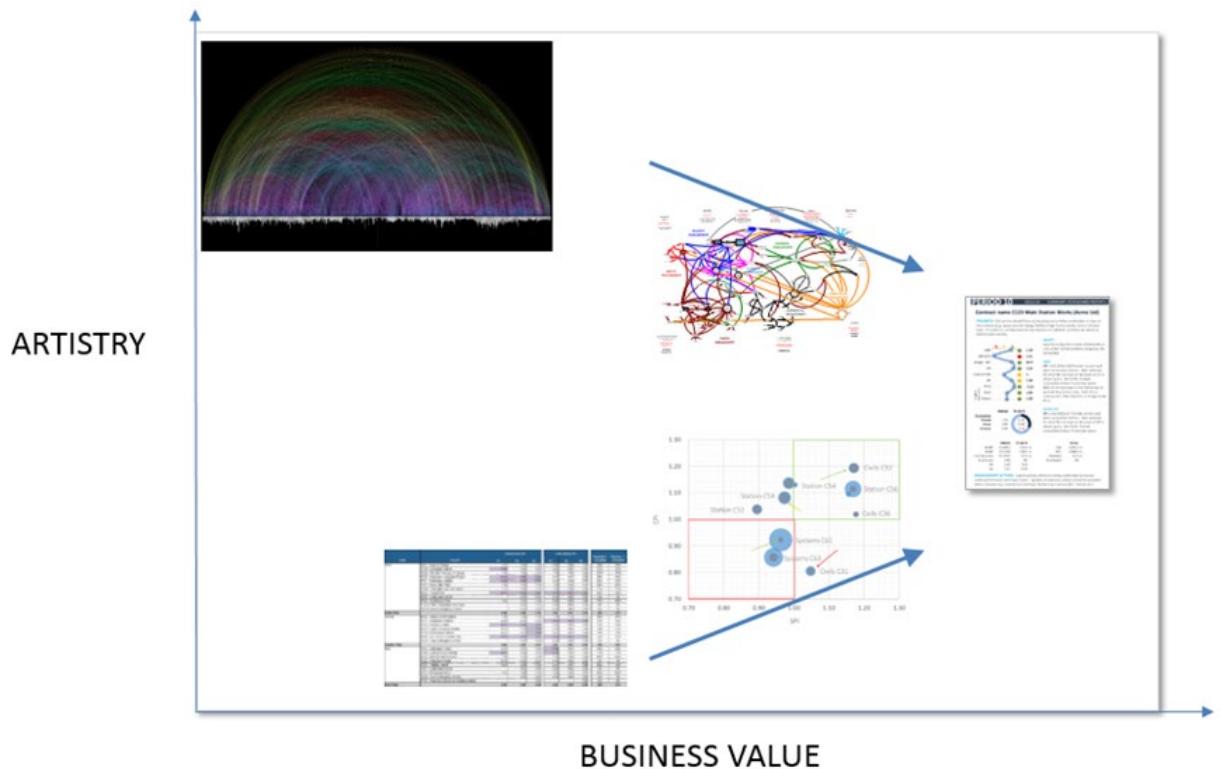


Figure 9. Warren, M. (2016). *Effective data visualization and performance reporting on Crossrail*. Data Visualization Summit

While the former question will be tackled the discussion, the latter can be unpacked analysing aesthetic elements of visualisation in the light of Tufte’s (1983) idea of the data-ink ratio²⁹. By maximising the data-ink ratio, according to Tufte (1983), one can design more compelling presentations of quantitative information, which are deemed more elegant and aesthetically pleasing as they minimise ‘chartjunk’ (i.e., unnecessary and potentially distracting information). If one were to calculate the data-ink ratio in the Project Dashboard (figure 4), Programme Dashboard (figure 8) and the summary page from the Board Report (figure 10), one would see the ratio steadily increase with

²⁹ Data-ink the non-erasable ink used in the visual presentation of quantitative data. On the other end, non-data-ink is ink whose removal would not compromise the information content of the graphic (in this sense, is the ink used for scales, labels, shades, 3D effects, etc.). According to Tufte (1983) the data-ink ratio is the proportion of ink use to visualise actual data compared to the total amount of ink used in the entire display (which include non-data-ink information). Tufte (1983) advocates for the following five minimalist “laws”, namely: 1) Above all else show the data; 2) Maximise the data-ink ratio; 3) Erase non-data ink; 3) Erase redundant data-ink; 4) Revise and edit. According to Tufte (1983, p. x): “A large share of ink on a graphic should present data-information, the ink changing as the data change. Data-ink is the non-erasable core of a graphic, the non-redundant ink arranged in response to variation in the numbers represented”.

the progressive reduction of narrative and detailed level information. This is an instantiation of the intuitive aesthetic judgement which any user would make in the observation of the three images: It is apparent that figure 10 complies with more intuitive ‘aesthetic concepts’ (Sibley, 1959) typical instances of which are balance, integration, harmony, dynamism, and beauty. In this sense, the ideal of the ‘beautiful picture’ seems to be intuitively possible mostly in relation to high-level visualisations, such as figure 10 below, which compared to the Project Dashboard, include a minimal amount of what Tufte would call ‘chartjunk’.

5.7.4. Artefacts that attract attention and pre-form conversations

The affordances enabled by the design features of the poster, together with the strategic physical location in which it is displayed, make of it a visualisation that not only supports the activity of interpretation but also sustains conversations and pre-forms interactions:

The poster simply is the focal point of my office [...] and acts as a conversation magnet. People come in and they are immediately struck by how much information there is on the poster and want to understand their own information and then their information in context. I have conversations with people where I simply explain to them the reason why, ‘I think we have a concern about your project is because the data, have a look at the poster, the data is telling me this, this, and that’. Among other things, it’s the tool that facilitates the next conversation (senior manager 1).

This poster is put together every four weeks by Programme Controls, with several iterations and the addition of comments (e.g., the colour-coded text boxes that can be seen in figure 8 at the margins of each column). Additionally, after the definitive version is accepted and printed, the Director of Programme Controls uses a red marker to highlight specific figures at the margins, and this activity of adding marks has the specific purpose of increasing visibility (see Cotgreave *et al.*, 2017) to pre-form interaction:

This poster sits on the wall in the program delivery boardroom and becomes a reference tool for people to orientate themselves with where the hotspots on the program might be. People come into the room in the morning, they see the poster on the wall, and whilst everyone is getting a cup of coffee, they're browsing the poster visually, and because I have gone through, with a big red pen, and circled areas on the poster, they automatically become my seeds of influence. The directors might not realise it, but when looking at my poster, their eyes will be drawn subliminally to specific information. [...] Adding marks is the last thing that happens [*in the construction of the poster*]. So, [*controls engineer 1*] produces the data set, cleans the data, and then she gives it to me as a draft, and we go through, and I highlight to her the things that I want to put into commentary. There are lots of commentary boxes, either red or green boxes based on whether the news is good or bad. Where I've marked with the pen is where I am deliberately provoking people to read more about that particular project (senior manager 1).

For these reasons, not only do the features and materiality of the poster support conversations but also additional layers of interactions – such as the marking with a red pen – create matters of concerns for the board that have been made more prominent by a senior manager. This draws attention to how subsequent manual iterations, beyond the supra-textual level of the reporting document (Kostelnick, 1996), can act as factors that socially organise distributed cognition in project organisations (Whyte *et al.*, 2016). According to a board member, the poster does that by contributing to break knowledge silos in the organisation:

It genuinely helped the project and the senior management team to understand the underlying trends, not just the snapshot of, let's say, P10, but to understand the history better, and the journey, and not get side-lined with the noise in the signal. It also helped people understand things outside of their direct field of knowledge. For example, the finance people obviously understand finance really well. But within finance, the indirect cost team understand the indirect cost, they don't really historically so much understand the contract cost, and vice versa. And they haven't got a clue about what the commercial team are doing, etcetera. So, what this did, was help break down silos of knowledge, and get people to understand the linkages between the different silos. So, that was perhaps implicit, just over time they understood it better, and that's very important (board member 2).

Board member 2 highlight how visual artefacts that aims to provide a ‘big picture’ of programme delivery can, creating connections and associations among performance areas, subliminally induce people to go beyond their thematic remit and explore information that relate to broader organisational challenges.

5.7.4. Keeping technology simple

Reporting dashboards in are “among the most important carriers of visual knowledge because they serve both as an interactive communication tool and as an individual thinking tool” (Henderson, 1991, p. 459) in complex programmes. This function as an individual thinking tool is not only connected to practice, but also to the production of the artefact and the choice of keeping its realisation process largely not automated. In fact, the poster is realised copying and pasting information from Excel files and derived from Prism, and its construction requires manual intervention, even though the template is standardised in its format. This manual process of construction – which is connected to the idea of learning by self-reporting discussed earlier – is kept in place on purpose, to make the construction of the poster a learning opportunity for the controls managers involved in the process.

According to the designer of the poster, the ‘semi-automatic’ nature of this visualisation is of great importance for the following reasons:

Because it was a semi-automatic, and because I needed to look at it, and I needed to physically copy paste, I was quite happy with that because it forced me to look at it, and therefore go ‘oh, this has changed’, or ‘that’s changed’, when I did my checks compared to last month. I came out of the process not only with the answer but with a view of the changes, and the new questions, which I wouldn’t have got if it was a super expensive, whizzy, automated tool. I don’t have a problem with it being not fully automatic. It prompts things. And I think that’s invaluable, and you might have noticed on the poster, what we then did was annotate it. So, we looked at the data, and then put up questions, ‘why is this like this?’, and these were coloured green and red to highlight the good news and the bad news. So, I think it is the right mix of automated enough

so it didn't take a week to do [...] but not so automated that you didn't actually get to play with the data and of course learn from playing with the data (senior manager 2).

The evidence from senior manager 2 reiterates the importance of individual and manual engagement with the artefact's template, as a process that prompts reflection and questioning of the information provided and their presentation. Lack of total automation in the production of reports and visual artefacts can, therefore, be a strategic decision in trying to ensure that selective patterns of action can emerge from the design of artefacts (see Pentland & Feldman, 2008). The involvement of interactors in the iterative and manual realisation of an artefact – or report – can hence support the development of a narrative logic (Garud et al., 2008) that impacts the agency of the interactor and their decision-making processes, both in relation to the 'design mode' and 'use mode' of an artefact (Orlikowski, 1992). From this perspective, the engagement with visual templates in the creation of reports can become an instrument for interrogating possible futures and, drawing upon the limits and discrepancies of the visual tool itself, enables reaching decisions that are context-dependent.

Additionally, the idea of learning by 'playing with the data' is an instantiation of how visual-material artefacts can be involved in the process of transformation of what is knowable, which involves a playful and evocative interactive dimension (March, 1987). Additionally, the decision of keeping the dashboard production semi-automated is connected with a deliberate effort in trying to avoid the assumption that one preconfigured software or model will perform reliably in every future application and that the decontextualized crystallisation of good ideas and good designs will lead to standardised good work (see Henderson, 1998). This is of particular importance, because highly automated software packages for information visualisations (e.g., Tableau) run the risk of causing the loss of the messy, trial-and-error and patched-together nature of the design process (see Stigliani & Ravasi, 2012). In this sense, abstract knowledge in "prepackaged formats may serve the purposes of review for busy executives, but such standardization can result in slippage and misfit between plans, appropriate action, and anticipated outcomes" (Henderson, 1998, p. 170).

5.7.5. The project performance summary and the standardisation of visual features

As the evidence in this section of the case study suggests, the worm diagram can consistently articulate its potential in material artefacts that enable comparability and emergence of associations. The poster format fosters comparison among the visual patterns more than an indirect mental association of the patterns retrieved by memory after having seen each project dashboard would. As it can be seen in figure 8, each project in the poster contains a concise presentation of the first and third column of the Project Dashboard (figure 4); in this sense, the information is more than the diagram itself. To illustrate how the worm diagram, thanks to its optical consistency and visual features, can relate to different audiences, it is insightful to look at the program summary page in the Board Report (figure 10).

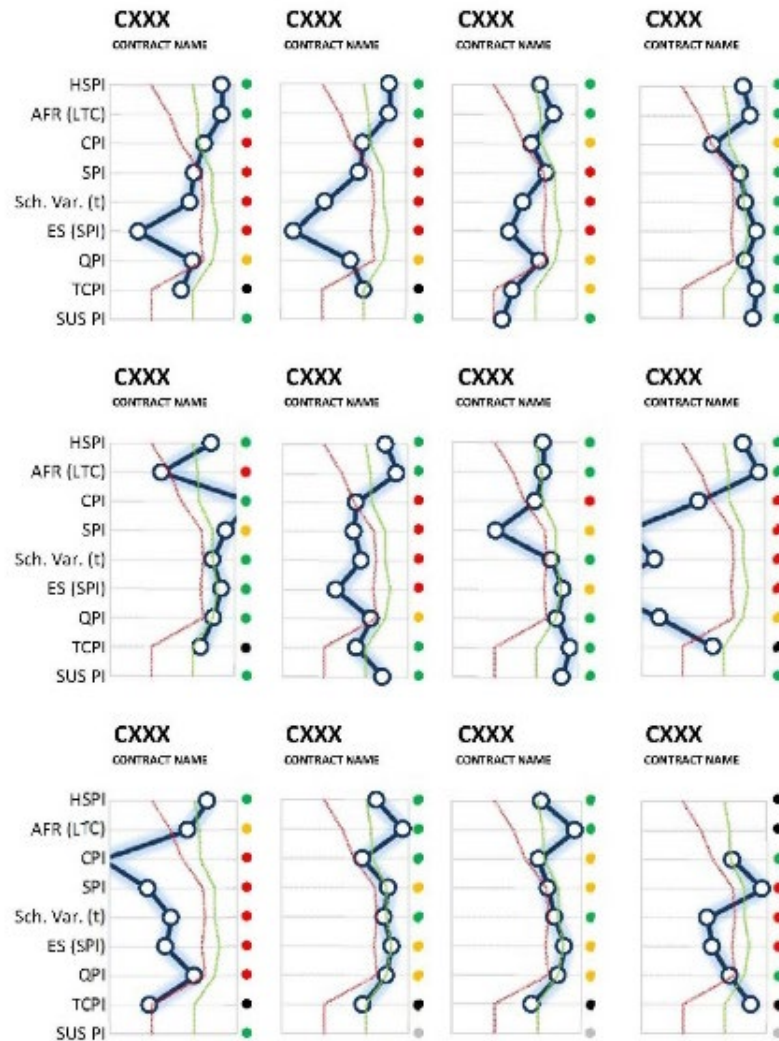


Figure 10. Project Performance summary page in the Board Report (anonymised)

The Board Report is targeted at Non-Executive Directors. The information about project performance in the board report (figure 9) is a further abstracted presentation of the worm diagrams in the poster, which in turn are derived from the more detailed descriptions in the correspondent project dashboards. The presentation of diagrams is achieved in an optically consistent manner, employing the same figures that can be found in the other artefacts discussed earlier. In this sense, the constant re-occurrence of consistent patterns and shapes aims to enable interactors to develop a mental model of how to engage with the different yet similar features of each report (Norman, 2013; Murray, 2012). The development of optically consistent visual features (Latour, 1986),

supposes an extent of centralisation and standardisation in the development and implementation of the visual templates of the reports. In this sense, as a control engineer illustrates below, there is often an effort in trying to create visualisations that can simultaneously be deployed in different artefacts, thereby creating a sense of consistency and familiarity among the artefacts produced in the setting:

If you can come up with a design that can relate to more parties and audiences at the same time you're making a product that's far superior to another that requires more outputs (controls engineer 4).

This standardisation not only is a practical requirement for the construction of the dashboards (Dambrin & Robson, 2011) but also aims to ensure the development of patterns of actions through the routinized engagement of users that are acclimatised with the features and purposes of each report (see Feldman & Pentland, 2008; D'Adderio, 2008). In this sense:

In a reporting intensive programme like this one a key concern is standardisation. Once the reports are designed, they need to change in a way that is coordinated. So, every single contract report, for the major reports, is identical [...]. So, you know how to read it, you know that on the right-hand side is all the data, and it's the same data you see on the poster [...]. And you have the worms, in the place where you expect them to be. It just helps you and then also, you have that mix of pictures, and diagrams, and graphs, and text put together that makes look around for what you are looking for (senior manager 4).

As the evidence suggest, the deployment of visual conventions that are consistent is one of the important elements involved in enabling the interactors “to place visual codes into the slots of mental schemata [...] and by activating schemata, generic conventions foster user expectations about the whole message” (Kostelnick, 1988, p. 38). Together, these features drive the visual rhetoric of each document, within the broader domain of the visual language and conventions that characterise the reports in the organisation. The systematic re-occurrence of partly standardised visual features creates a degree of familiarity with the report for the acclimatised reader.

The familiarity created with the reporting visualisations informs the designers' choices in the creation of the reports. This is evident in figure 9, the most striking feature of which is that on the summary page there is no quantitative KPIs. Everything that is presented, as a high-level nonreferential visualisation (Ashwin, 1984), is the pattern of the worm diagrams, the name of their KPIs and their RAG status. This page of the board report unveils the worm diagrams in their purest form, and it is thanks to this visual configuration that it is possible, just by glancing at it, to grasp the specificity that characterises each project in the program:

Have you ever looked at viruses under a microscope? They wriggle. I look at them, and I treat each performance worm as the DNA of each project. You can look at worm [A], and it's very straight. But then, I look at the worm [B] and it's all over the place, some of it is not even able to be shown. Each worm tells a different story, and the worm only comes into its own in this visual. People see it on the dashboard all the time. [...] Only when you look at the worms side by side, you get a general sense of just how different each project is performing. No two projects are alike, and the worm diagrams do a great job of showing just how different each project is (senior manager 1).

Senior manager 2, referring to the comparability of the patterns, defined the worms as “contract fingerprints” that enable the users to quickly form a typified understanding if a project is “a basket case, chaotic, wriggly, consistent, or a gold star”. The contract fingerprint is visualised in figure 11, which is taken from the presentation that senior manager 2 gave at the Crossrail Leadership Conference to illustrate the functioning and thought process behind the design of the worm diagrams and the idea of associating them to illustrate the difference in patterns.



Figure 11. Warren, M. (2016). *Effective data visualisation and performance reporting on Crossrail*. Data Visualization Summit

As it appears from the summary page of the Board Report and the picture above, the diagrams provide a quick categorisation of how different projects are performing, in a way that highlights oddities among visual patterns and their heterogeneity. However, the designers in Programme Controls are aware that the summary page is not meant to be exhaustive. It has the purpose of helping users develop a quick yet comprehensive mental picture that affords an immediate appreciation of the complexity and heterogeneity of the programme, while highlighting high-risk projects.

The great thing with the worm is that you can look at that and just visually encapsulate how it is broadly performing, as an individual contract across some of the key lead and lag indicators. [...] It's quite a nice, easy, quick scan, and if you want to then follow that through, then you can dwell into the details, that information is still there, it's just not included in the board report anymore. I can live with that, and it's a good example where the teams that produced this information now said 'I think it's now time for information to be lessened', and in the scheme of things that's a good example where they have taken that initiative, rather than it just being pushed down from a board (board member 1).

The piece of evidence above is significant in that it highlights several aspects. Firstly, the objective of the worm diagrams is not to prompt an over-simplistic attitude towards megaproject delivery, but to support a high-level interpretation of the delivery status of the various projects and their areas of criticality. Secondly, it points to a bottom-up initiative taken by Programme Controls in presenting information to the board visualised innovatively. This, in turn, is a manifestation of how visual conventions

supported by a certain level of optical consistency and predictability (Latour, 1986), can “prompt rather than stifle invention [...] and pervade different forms of design” (Kostelnick & Hassett, 2003, pp. 5-6). It also shows that visual conventions in Crossrail acquired ‘conventional currency’ (Kostelnick & Hassett, 2003). In a sense, these conventions are not only pushed for by the executives but also benefit from the support from individuals and teams that are lower in the organisational hierarchy. It is those teams that, through their design work, rely on the inventory of conventional codes and templates to try to innovate how information is reported.

From the perspective of Programme Controls, the rationale behind the realisation of figure 10 was to make sure the conversation in the board was about performance:

Ultimately, if someone wants the data behind it, they can go and find it from the reporting platform, they have access to that. We are producing these reports because there’s discussion being held on it. It doesn’t matter if it’s 300, or 301, or 302. Doesn’t make a difference. It matters how far the progress is, and what’s the change (control engineer 1).

However, the visualisation in figure 10 is controversial. This, in turn, points to the process of how design criteria and conventions become accepted in the programme, and how a trade-off between bottom-up and top-down innovation is achieved. According to a senior manager:

It does draw your eye, I mean look at [*worm B*], it’s off the graph, for me then, I might look at this and I’d go ‘oh, I wonder what’s happening there’. Normally, I would have read the detail on the contract page, but it’s not there anymore. Why is [*project B*] falling off? [...] For me that might be a question to ask if I was a board member, I’d say ‘what is going on at [*project B*], cause it’s off the page, but you hadn’t written anything about it, are you going to get it back on time? (senior manager 3).

In this sense, the level of abstraction reached in figure 10 may be too risky according to some senior decision-makers. They are not questioning the value of the worm

diagrams in supporting understanding of the complexity of the megaproject, but they believe the relational abstraction that one can make from an assessment of the worm diagrams without KPI scores to be potentially too vague. According to a board member commenting on figure 4:

That's probably where you say: 'I'm not so sure I would have given that up'. Ultimately, it's getting close to just sort of a comfort picture, and at the end of the day, you could have lots of worms that look very straight. They look so covered because they all look consistent, but they could all be at the wrong end of the scale. [...] You are pulling a whole heap of information on just one page. I would like to see the numbers, next month we'll probably say, 'put the numbers into it, worms without numbers are not enough' (board member 1).

The evidence above illustrates the importance of the deployment of design features that can constrain the interpretation of visualisations (see Cardinaels & van Veen-Dirks, 2010). The board member's suggestion to reintroduce the quantitative KPIs aims to reduce the possible associations that figure 10 can prompt thanks to its visual-relational properties and interpretive ambiguity. In this sense, the concern of board member 1 instantiates the importance of Crossrail's internal activity of scrutiny (discussed in section 5.1.) which aims to ensure that visualisations are not mere 'comfort pictures'.

This final section of case study has illustrated how visual artefacts designed to support the development of associations and relations among many projects and indicators can become influential in the delivery of a megaproject. By highlighting the trade-offs among notions of functionality and aesthetics in the design of data visualisations, this section of the case study has identified how specific features for the design of visualizations are employed to construct artefacts that engage the users and help them form a sense of the 'bigger picture' of megaproject delivery. This process is also supported by the construction and population of the templates of visual artefacts as opportunities for learning and goal discovery.

5.8. Concluding remarks

This chapter has articulated in a detailed manner a qualitative case study concerned with the design and practice of accounting visualisations in the Crossrail megaproject. In so doing, it has investigated the question of how and why visual artefacts become influential in megaproject delivery, and how the design of such artefact shapes and supports practices of future use. Other concerns that were explored in the findings relate to the importance of aesthetics and functionality in the construction of visual artefacts, and how visualisations can drive proactive behaviours by being continuously adapted to specific programme delivery challenges. The analysis of the empirical material in the findings was guided by the comprehensive articulation of affordance as interaction possibilities, visual conventions as the language deployed by the designers in the construction of artefacts, and visual literacy as pragmatic competence require to engage with visual information. From the empirical material several key concerns emerged that enrich understanding of the question of how and according to which criteria reporting designers construct dashboards and performance visualisations to engage with complex organisational settings. Based on the insights from this chapter, the theoretical argument of this thesis can be further developed in the following discussion.

6. PRINCIPLES FOR THE DESIGN OF ACCOUNTING VISUALISATIONS

6.1. Introduction and overview

A distinction is drawn by arranging a boundary with separate sides so that a point on one side cannot reach the other side without crossing the boundary (Spencer-Brown, 1969, p.1)

Following on the presentation of the findings in the case study, this chapter focuses on the theoretical implications of this project. The key question guiding this research was the identification of design principles that make accounting visualisations influential in the engagement with the complex and dynamic delivery of a megaproject. These research concerns guide the following discussion. This section explores and contributes to literature that investigates how visualisations become performable in complex settings (i.e., Pollock & D'Adderio, 2012; Pollock & Campagnolo, 2015; Quattrone, 2017), their incomplete and ambiguous information content (i.e., Qu & Cooper, 2011; Dambrin & Robson, 2011; Jordan et al., 2016), and their rhetorical and persuasive power (i.e., Thompson, 1998; Espeland & Stevens, 2008; Busco & Quattrone, 2015). The theoretical concepts that guided the combined exploration of these issues are the notions of affordances, visual conventions and visual literacy, which were extensively articulated in the third chapter.

One aspect that emerged from the case study is the effort that reporting designers in Crossrail put in the creation of visual artefacts that are expected to achieve 'goodness of fit' (Simon, 1996) with precise challenges and phases of megaproject delivery. Their effort is grounded in the belief that the design of visualisations can influence interaction by means of their material configuration, and that design choices affect interaction. To explain the criteria thanks to which Crossrail's reporting products shape interaction, in this section the study theorises five interlinked principles that emerge from the case study. These design principles are (1) multimodal balance; (2) visual relationality; (3) optical consistency; (4) functional beauty; (5) the magnification of

incompleteness and the visualisation of consequences. These principles were developed based on the insights gained from the case study and the visual analysis of the reports, but they are to be understood as theorisations that go beyond the pragmatic criteria adopted by the designers. As will become clear from the following discussion, specific criteria (e.g., principles 1, 2 and 5) are theoretically informed articulations based on pragmatic design concerns adopted by the designers themselves. The remaining principles (i.e., 3 and 4) are theoretical syntheses that emerged at higher-order of abstraction on the basis of the study of the artefacts but were not knowingly articulated by the designers.

This section shows how the theorisation of these five principles contributes to the understanding of how the practical construction of accounting visualisation, and how visual artefacts become influential in complex organisational settings. A crosscutting theme that guides the following discussion is a concern with providing criteria to exert control of direction over the ambiguous relationship between designers and users (Orlikowski, 1992, 2004, 2007) – in which designers strive to anticipate how users will interpret artefacts in interaction – that is grounded in the possibility of interactors choosing to do otherwise with a technology at hand.

6.1.1 Engaging with the multiplicity of the megaproject: The principle of multimodal balance

A central concern that emerged from the analysis of Crossrail's reports is a focus on the idea of 'balance' as a criterion for the design of visualisations. As Cooper et al. (1994) argue, the very idea of 'balanced accounts' indicates that there has always been in the accounting discipline an element of aestheticism which dates to the origins of double-entry bookkeeping (see Graves et al., 1996; Thompson, 1998; Puyou & Quattrone, 2018). However, here the focus lies specifically on how ideas of balance inform the practical construction of visual artefacts that are designed to be "not only errorless but also compelling, elegant, and even beautiful" (Espeland & Stevens, 2008, p. 422). This design criterion is theorised through the development of the notion of

multimodal balance, and the discussion shows how the principle not only relates to the modes of presentation of the information that populates dashboards (Qu & Cooper, 2011; Cooper et al., 2017) but creates inevitable tensions in the ways in which specific features call for attention and inform interaction.

Multimodal balance is the harmonious visualisation of heterogeneous types of information (i.e., narrative, quantitative and graphic) that require different *modes* of presentation. A mode is a socially shaped and culturally given resource for making meaning, and different modes – such as writing, image, and colour – offer various potentials for meaning-making (Vinnari & Laine, 2017). In this sense, multimodality is “the combination and orchestration of multiple modes in communicative acts” (Höllerer et al., 2017, p. 2). The potentials of different modes influence their deployment in specific interactional and communicative contexts. Accordingly, multimodal balance is a substantive qualification of multimodal design:

Multimodal design refers to the use of different modes – image, writing, colour, layout – to present, to realize, at times to re-contextualize social positions and relations, as well as knowledge in specific arrangements for a specific audience. At all points, design realizes and projects social organization and is affected by social and technological change (Kress, 2009, p. 139).

Multimodal balance, as a specific instantiation of multimodal design, draws from a variety of forms of presentation to induce users to engage with the multiplicity of megaproject delivery (Nocker, 2006; Cicmil & Hodgson, 2006), connecting aesthetic and functional ideas through coherent designs.

As it emerges from the evidence about the rationale behind the design of the Technical Dashboard (figure 3), presenting substantial amounts of data in a table format can decrease the visibility of information that require immediate identification. As the participants suggest, presenting information in a data table format can fulfil the needs of interactors with advanced accounting knowledge (Cardinaels, 2008) that have a

profound understanding of granular performance information (e.g., project managers and Executive Committee members). The objectives of the Project Dashboard are different as it aims to support higher-level conversations about performance and delivery between project managers and programme executives. According to the designers, it was constructed balancing its information requirements to foster an overall appreciation of the delivery requirements for specific projects. Achieving a balance among an artefact's multimodal features emerged as a design choice to enable the emergence of affordances that clarify, complete and extend what already exists in data tables.

Capitalising on a visually orchestrated template of quantitative, visual, narrative and colourful information, the reporting designers articulated an interface that shapes and mediates interaction in use (see Simon, 1996). Such “interfaces represent technologically mediated affordances that encourage certain actions [...] and make others less likely” (Kornberger, 2017, p. 180). As the evidence suggests, the thematic categorisation of the multimodal material affords and facilitates the development of a visual inventory of concerns (Quattrone, 2009). Not only this articulation provides an analytical template for the composition of knowledge of management matters (Quattrone, 2015a), but it also functions as a formal list of issues to be discussed in meetings. As the evidence shows, this inventory aspect is influential in board meetings to ensure that the ongoing discussion touches all the aspects of the dashboard. This consideration is significant beyond its ritualistic aspects, as it aims to ensure that no single category of indicators monopolises the discussion. Additionally, the quotes by senior manager 1 (see section 5.4.2.) show how multimodal design helps interactors drawing from their experience of similar projects to come to context-dependent decisions. In this sense, different modes support reflection on the project by relying on narrative, visual, and quantitative information – each of which has different potentials for meaning-making. In other words, associating thematic delivery information to different modes increases the prominence attributed to specific information categories and supports more comprehensive and nuanced evaluation (see Lipe & Salterio, 2000,

2002). That is why the designers reported that only a subset of information that can be visualised is included in the graphical layout.

In this sense, not only “the rhetorical composition of the figure that the visualisation affords always implies the choice of a path” (Quattrone, 2017, p. 596) to navigate the complexity of the visualisation, but the materiality of the artefact and the prominence of its features make different value dimensions and indicators more evident and engaging. As the participants from Programme Controls suggest, this is done to stimulate interest and facilitate understanding of complex delivery information, which often requires the inclusion of narrative information in the textual mode. Consequently, the layout of the Project Dashboard and its extra-textual elements aim to reduce the chance of some indicators and parameters being systematically prioritised over others in a decontextualized manner. Instead, its design aims to prompt a holistic appreciation of a visualisation that requires time and scrutiny to be understood. To achieve this goal, the designers created a layout that aims to help users to keep in mind a broader range of dimensions and indicators that require reflection to be contextualised and made meaningful in the delivery of the megaproject.

Specific features of the dashboard are indicative of the designers’ interest in fostering engagement with an inclusive set of indicators, which in turn afford heuristic processes of understanding and interpretation. These concerns with balance can also be identified in the fact that the dimensions of the Crossrail objectives (i.e., safety, time, budget, world-class) are declined into visual features of performance visualisations. In the worm diagram (figure 7), the four criteria are the parameters according to which the visual pattern is generated and are all equally weighted. The non-hierarchical visualisation³⁰ of performance categories affords negotiation among values in decision-making and highlights how visualisations can be designed to prevent one

³⁰ Although the KPIs in the worm diagram are arranged vertically, there is no hierarchical criterion that guides their deployment in the visualisation. As it emerges from the findings, the crucial element in the interest of the worm diagram is its visual pattern, considered in its entirety and not its individual KPIs that can also be found elsewhere in dedicated sections of the reporting documents. In this case, vertical disposition does not imply a hierarchy of worth but is simply a design necessity.

given value dimension to prevail univocally over the others (Cardinaels & van Veen-Dirks, 2010; Lipe & Salterio, 2000) by means of the artefact's visual design. The attempt of moving beyond a bottom line and towards a more nuanced appreciation of value dimensions is materialised in the dashboards and diagrams constructed to support discussions and decision-making (see Cooper et al., 2017). This example illustrates concretely how the design of visual artefacts can support the activity of “praising doubt and transforming knowledge imply[ing] that accounting can help creating issues and concerns worth considering while it cannot authoritatively end discussions” (Mouritsen & Kreiner, 2016, p. 29).

The concern with achieving multimodal balance is also instantiated in how the worm diagram is positioned in the dashboard to attract attention. The purpose of this diagram in the economy of the visualisation is to enable the user to *subitize* (Pollock & Campagnolo, 2015) performance information before *dwelling* (Comi & Whyte, 2017) into the details of the dashboard. However, subitizing information contained in the diagram is not meant to exhaust the usability of the artefact. Instead, it provides an overview to synthesise information about the project, thereby creating a frame (Themsen & Skærbæk, 2018) for subsequent interpretation of detailed information. The deployment of the diagram in figure 4 shows how subitizing does not only relate to heuristic information processing but can serve to prompt engagement with the visualisation and the matters of concerns made visible through the interrogation of the artefact. The affordances of this dashboard are illustrative of how visual design features can prop out interactions and pre-form interpretation.

The principle of multimodal balance shows that ideals of balance (Cooper et al., 1994; Cooper et al., 2017) and the ‘beautiful picture’ (Espeland & Stevens, 2008; Pollock & D’Adderio, 2012) contribute not only to the aesthetic qualities of an artefact but are ultimately specifications that can augment its interactional possibilities. The discussion of this principle provides insights into how multimodal balance is a notion that the designers deploy in the practical construction of visual artefacts to induce users

to engage with the ever-unfolding nature of the megaproject. In so doing, this criterion highlights how designers can rely on different modes of presentation to work against reductionist ideals of correspondence and attract users through diverse aesthetic forms and patterns.

6.1.2. Creating associations and the construction of the ‘big picture’: The principle of visual relationality

The mind is insatiable for meaning, drawn from, or projected into the world of appearances, for unearthing hidden analogies which connect the unknown with the familiar, and show the familiar in an unexpected light. It weaves the raw material of experience into patterns, and connects them with other patterns (Koestler, 1975, p. 390).

The criterion of multimodal balance theorises how designers can deploy multiple forms of visualisations to create compelling numerical pictures to engage with megaproject delivery. However, to create meaningful associations among the emerging matters of concern and diverse projects that constitute the programme, visualisations also have to "connect the unknown with the familiar, and show the familiar in an unexpected light" (Koestler, 1975, p. 390). To theorise these concerns about the design of accounting visualisations, in what follows I develop the principle of *visual relationality*. Visual relationality is a mode of presentation of information that supports the creation of associations and connections within and among features of visual artefacts. In so doing, it highlights the megaproject's interconnectedness, heterogeneity, and emergent properties.

Visual relationality is a core criterion according to which the poster (figure 8) and the summary page of the board report (figure 10) are constructed. The evidence illustrates how the patterns of the diagrams are designed to be compared side by side and are associated in the poster, which condenses the core performance information of the multi-billion pounds programme into one visualisation. As shown in the case, through

their juxtaposition and comparability, the diagrams facilitate the evaluation of different performance patterns thanks to their memorable shapes and forms. The affordances of the visualisations in figures 8 and 10 are thus augmented by the relational properties that the diagrams acquire if put side by side. The visual and relational comparison of such patterns and their capacity of facilitating diagnosis of issues and appraisal of the heterogeneity of the projects are, according to the participants, the most significant affordances of the poster. As the evidence on the design and use of such artefacts shows, these visuals do not strive for referentiality between the projects and their performance, nor are they designed with the ideals of representational accuracy (see Kornberger et al., 2017; Jordan et al., 2016) and exactness. Instead, they point towards the creation of novel interpretations of the meaning of performance information.

These design features not only show how the design of dashboards and reports can enable “the perception of emergent properties” (Ware, 2012, p. 3) that cannot be faithfully represented, but also show that the interplay between aesthetics and functionality helps managers to form a synthetic sense of the ‘big picture’ of the programme’s complexity (see Boland et al., 2008). However, the ‘big picture’ is not understood by managers in Crossrail as an absolute and all-encompassing representational ideal (Kornberger & Clegg, 2011). The participants involved in the design and use of these artefacts often stressed that they are practised as prompts to form a ‘*gestalt*’ of the programme’s performance. The affordances of the artefacts are instrumental in pre-forming interpretation thanks to their capacity of articulating a new image on which to base detailed level interrogation. In this sense, the visual configuration of the worm diagrams shows how the affordances of visual designs have to be “sensible themselves, and they have to help people making sense of the situations they face” (Weick, 2004, p. 41) when engaging with complex and dynamic environments.

The information content of the poster often calls for subsequent analysis and requires dwelling into the details of more granular information contained in different reports

(i.e., Project Dashboard and Board Report). As the evidence from the designers in Programme Controls shows, they conceived of its ‘use mode’ (Orlikowski, 1992) as a diagnostic tool for the identification of delivery areas requiring attention. Hence, the designers did not think of it as a mere ‘answer machine’ (Burchell et al., 1980). The programme dashboard, by means of its design and features that are visually in relation and tension, aims to prevent the risk crystallising decontextualized indicators and blinding the users towards alternative perspectives. It is hence intended to prevent the risk that “while we are fully immersed in the big picture no space is left for alternative perception, and we experience only a small glimpse of the many possible futures” (Kornberger & Clegg, 2011, p. 155).

These concerns are particularly relevant about how the design of the diagrams in the poster and the report supports their interrogation and induce questioning the ‘matter-of-factness’ of representational assumptions. The evidence shows that the patterns as such – which are also referred to as the ‘contract fingerprints’ and the ‘DNA of each project’ (see figure 11) – are a subject of investigation in their own right. It is in this sense that

Successful numerical pictures influence the ontology of what they represent. The picture becomes its own subject, replacing, in the comprehension of the observers, what it was originally intended to depict (Espeland & Stevens, 2008, p. 426).

The articulation of visual patterns in the case shows how designers can create a specific type of visibility in the realisation of organisational artefacts, a visibility that highlights the interconnectedness of the megaproject. This visibility can become a reality (Hopwood, 1987) which shapes future interpretation and engagement on the part of the users, by facilitating the creation of associations among different projects and indicators. The visual relationality of the features of the poster is an instantiation of how, rather than viewing representations as spaces to be ‘seen’ in visualisations, to theorise on the power of these artefacts it is critical to focus on “the margins of these

representations, that is, on the imagining process prompted by what is referred to by images and visions but not explicitly defined” (Quattrone et al., 2013, p. 5).

The artefacts in figure 8 and 11 have commonalities with artworks characterised by what the designer and art theorist Gyorgy Kepes (2014) calls *dynamic iconography*. The patterns in the poster fuse aesthetic qualities and functional elements in a visual artefact that evoke

Associations of great depth because of the sensory intensity of plastic values, and of great width because of the associations discharged by the linguistic basis. Color, shape, line and symbol attain an organic unity and thus train the user to form into an organic whole his own experiences of the divergent qualities (Kepes, 2014, p. 209).

The visual patterning and the organisation of the signs are unified into a common dynamic structure, supported by their consistency and conventional features. The relationality created by the visualisations connect knowledge of the projects’ performance, previous experiences, and contextual factors in unexpected and potentially novel arrangements. The visibility that these artefacts create on the organisation is however tied to their interpretation in interaction. Although the visualisations contain observable relations among and between the patterns, colours, values, and commentary sections, their intended affordances are always dependent on the interactors’ interpretation in action (Henderson, 1999) – which is inherently phenomenological and unreducible. In this sense, they are “objects and performances that induce but do not dictate analogical considerations” (Barry & Meisiek, 2010, p. 1505).

The relational properties supported by the artefact’s construction are an instantiation of how designers establish meaningful connectedness among the visible forms and the *hoped-for* interactional possibilities. The fact that the message can only be hoped-for

highlights how the rhetorical relationship between designer and user, where the designer strives to anticipate how the user will interpret the features of an artefact, is uncertain, ambiguous, and flexible (Qu & Cooper, 2011). However, to counteract the tendency of nonreferential conventions – such as the formal features of the worm diagram – to be too ambiguous, it is essential to identify design cues that can constrain and guide interpretation (Cardinaels & van Veen-Dirks, 2010). This is a precondition for the designers to *deliberately* exert control of direction over the associations prompted by the material outcomes of their work. One way this occurred in the case was through the reintroduction of the quantitative KPIs advocated by board member 1 about figure 10. The reintroduction of the KPIs is an attempt at constraining interpretation through the quantitative appeal of the numerical mode (Porter, 1995), in a way that would counterbalance the interpretive ambiguity of visual-relational properties of the diagrams. In this sense, as senior manager 3 pointed out, the identification of strategies that can prevent the risk of visualisations becoming mere ‘comfort pictures’ is essential, and it is necessary to keep in mind that the “aesthetic seductions of numerical pictures contribute to the temptation of misuse” (Espeland & Stevens, 2008, p. 430).

The principle of visual relationality theorises how Crossrail's dashboard and diagrams do not become influential *only* because of their interdiscursive appeal (Jordan *et al.*, 2016), simplicity (Pollock & Campagnolo, 2015) and mediating capacity (Pollock & D'Adderio, 2012). Instead, it shows how designers proactively rely on visual relationality to give presence to the megaproject's emergent properties, trying to discourage the user from a reductionist overreliance on decontextualized indicators. However, visualisations conceived in the light of the criterion of visual relationality are not to be understood as based on representational claims. The fact that these visual artefacts can analogically refer to the complexity of the setting is to be understood in terms of the goodness of fit between an interface and its environment (Simon, 1996). Additionally, the principle illustrates the importance of deploying visual features that can constrain interpretation. Such constraining activity can be achieved through specifications that pertain to the domain of the affordances in individual-level

interaction, or by relying on the properties of the visual language that holds together the visual artefacts in an organisation, which are discussed in the next section.

6.1.3. Normalising interaction with visual artefacts: The principle of optical consistency

The principle of optical consistency ties the emergence of affordances that are hoped for by the designers in the construction of artefacts with the visual language that they deploy. By optical consistency, I refer to the similarity, consistency and ‘family resemblance’ among reoccurring visual codes, features, and language the designers use in the creation of visual artefacts in a setting. In this case, it refers to the common language that characterises the reports detailed in the findings. The consistency of a visual language can contribute to normalising visual practices among both the designers and the users (Kostelnick & Hassett, 2003), thereby creating a productive ground based on which specific affordances can be detected and recursively emerge in interaction.

Optical consistency, according to Latour (1986), can make impossible things realistic and make possible objects more probable than others. In other words, conventional features can be deployed by designers to alter the domain of what is probable in practices of future use of visual artefacts. This is meant to grant a specific – albeit limited – control of direction over the interactional possibilities of such artefacts. By control of direction, I refer to what the designers can influence about how the visualisation attains and maintains the interest of the user in interaction. Optical consistency is as a substantive property of a set of artefacts practised by visually literate interactors (Messaris & Moriarty, 2005), whose literacy is based how a visual culture links material experience to a specific way of seeing the world (Henderson, 1999). The visual culture of an organisation is its material worldview, namely the instantiation of how the way of seeing reflects while shaping how individuals render the world through technologies of representation and calculation (see Rose & Miller, 1992; Carruthers, 1995).

To theorise on the optical consistency of Crossrail's visual language, it is insightful to consider how the worm diagram (figure 7) is a recurring feature of different reporting products. The deployment of layouts and supra-level design features – namely the formal visual elements that orient us perceptually and rhetorically when we encounter a document (Kostelnick, 1996) – is coordinated by Programme Controls in their activity of designing and putting together the different reports, thereby producing familiarity and creating a common ground to interact with the affordances of the visualisations. The worm diagram appears in Project Dashboards (figure 4), in the 'programme dashboards' (figure 8), and in the Board Report (figure 10). As the evidence shows, while remaining in the same configuration the diagram retains its capacity to engage and communicate with different audiences at various levels of programme delivery. The fact that the diagram remains constant in its design indicates that new visual conventions – and especially unusual ones – are not readily accepted and design choices suppose a level of path-dependency. Hence, establishing familiarity with artefacts that have different purposes and audiences can be challenging:

A visual language must circulate in the pure light of day to gain conventional currency [...] Conventions have to break through by winning the minds and hearts of users entrenched in the habits of existing conventions (Kostelnick & Hassett, 2003, p. 79).

Conventional visual features not only have to be relatively easy to recognise, recombine, and economical to imitate, but also have to establish a connection among the affordances of individual designs and the language that is common to the different artefacts. This shows how conventional features must solve common information design problems to become performable in a setting. In the light of these considerations, optical consistency emerges a substantive feature of a visual language that, despite not being a logical precondition for communication and interaction to happen (Kent, 1993), facilitates the emergence of interactional possibilities in the engagement with a family of artefacts.

Adding to recent interest in the enabling and constraining aspects of accounting visualisations (see Qu & Cooper, 2011; Pollock & D'Adderio, 2012; Jordan et al., 2016), optical consistency offers insights about at least two concerns. On the one hand, it emphasises the restricting implications that a shared visual language implies in the '*design mode*' (Orlikowski, 1992). In other words, the adoption of common visual codes and templates constrains the designers' creative capacity in the conception and realisation of organisational artefacts. That is because communication and interaction do not occur in a vacuum and factors such as visual culture (Latour, 1986) and the interactors' visual literacy, intended as their "fluency and literacy with signs" (Ewenstein & Whyte, 2007, p. 689), influence how they can interpret visualisations. Additionally, the design of interaction is constrained by interactors' understanding of how to *practically* engage with these artefacts. This capacity is influenced by the tacit knowledge which may not be formalizable in principle (Polanyi, 2009) and is linked to the interactors' experiential dimension.

On the other hand, the existence of a visual language is an important enabling precondition for the '*use mode*' (Orlikowski, 1992), as it ensures that distinct interactional possibilities are more likely to emerge in the engagement with a design artefact thanks to the conventional currency of its features. However, it is worth emphasising that while the material and design configuration of visual artefacts is a crucial determinant of the outcome of each interaction, interactors can choose to do otherwise (Orlikowski, 2007) while engaging with such technologies and this process is non-deterministic. In this sense, "we are left with an element of surprise, ambiguity, and instability even when a rigid convention is deployed in the most conventional of settings" (Kostelnick & Hassett, 2003, p. 224). Building on the discussion in section 6.1.2., optical consistency describes some additional mechanism designers can use to exert control of direction over the intrinsically ambiguous and open-ended rhetorical relationship between designers and users.

6.1.4. Designing the ‘beautiful picture’: The ideal of functional beauty

Reflecting on the optical consistency of a visual language enables the investigation of how aesthetic knowledge and values inform the design of visual artefacts. The theorisation of the notion of ‘functional beauty’ contributes to recent calls for research on the roles of aesthetic knowledge in the design and practice of material artefacts (see Ewenstein & Whyte, 2007, 2009; Stigliani & Ravasi, 2018). As Strati (2003, p. 54) argues, aesthetics is an

Intersubjective form of knowing [...] which is both individual and collectively constructed in the interactive acts by individuals of experiencing, understanding and judging through sense and taste.

As discussed in chapter three, aesthetics is connected to tacit knowledge and pragmatic competencies that cannot be fully intellectualised and informs and is informed by the designers’ aesthetic codes and professional expertise. The deployment of aesthetic codes in the design practice hence is a “professional judgment based on cultivated sensitivity” (Ewenstein & Whyte, 2007, p. 701) resulting from recursive exposure to aesthetic stimuli and conventions in a setting.

As it emerges from the case, a guiding criterion in the design of dashboards and reports in Crossrail was identifying viable trade-offs between aesthetic values (what they define as ‘artistry’) and functional values (or ‘business value’) – see figure 9. This trade-off emerged in the discussion of how they achieved the final design of the ‘programme dashboard’ (figure 8) and the summary page of the board report (figure 10). The designers contend the creation of visualisations that contain concise information about the entire programme require more attention to aesthetic considerations than the design of artefacts with a narrower scope. They also maintain that important design choices regarding inclusion and exclusion of information from the reporting documents were made based on aesthetic grounds.

Hence, in the design of visualisations that prompt the formation of a ‘big picture’ (Boland et al., 2008; Kornberger & Clegg, 2011), values that are not concerned with accuracy and referentiality (Kornberger et al., 2017) acquire more relative importance. Additionally, the case illustrated how the perception of the beauty of numerical pictures links to Tufte’s (1983) goal of the maximisation of the data-ink ratio. It appears that visual artefacts that strive for the development of a higher-level visualisation (figures 8 and 10) enable designers to achieve a higher data-ink ratio by minimising ‘chartjunk’. The maximisation of the data-ink ratio in ‘big picture’ representations leads to the development of numerical pictures that intuitively comply with aesthetic concepts such as balance, dynamism, and beauty. For the development of such artefacts, paying attention to the aesthetic attributes that make a numerical picture ‘beautiful’, thereby increasing its exciting features and attract attention, were deemed fundamental in the case.

Existing literature on the notion of ‘beautiful picture’ in business visualisations (Espeland & Stevens, 2008; Pollock & D’Adderio, 2012) illustrates how aesthetic values constrain the design of visual artefacts (Quattrone et al., 2013; Cooper et al., 2017). From this perspective, complying with the design application of ‘aesthetic concepts’ – typical instances of which are notions of balance, dynamism, and beauty – implies compromises and trade-offs around the information content of such visualisations, their meaning, and layout. For instance, as Pollock & D’Adderio (2012) and Pollock & Campagnolo (2015) show, there is a limited number of players that can be visualised as dots in the Magic Quadrant for it to offer completeness of vision while enabling the user to understand and quickly assimilate its information content. Achieving a balance between being too empty and too cluttered is assumed to be an aesthetic aspect that supports the functioning of the Magic Quadrant. However, despite pointing to a series of trade-offs that characterise the construction of visualisations, the extant literature has not theorised analytically the *status* of the aesthetic elements that make such numerical pictures ‘beautiful’ and how beauty relates to functionality in the design of numerical pictures.

The participants in the case contend that artefacts that help to develop a synthesis perspective on the programme should be aesthetically pleasing otherwise people would not be drawn to them, which in turn would compromise their willingness to engage and interrogate the artefacts. However, providing an analytical definition of the beauty of dashboards and accounting visualisations – intended as artefacts that are appraised in terms of functions, goals, and adaptation (Simon, 1996) – is not straightforward. That is because these artefacts are not appreciated for their own sake (e.g., unlike certain art forms) nor their beauty is merely accessory to their function (e.g., like a chair that, a part of being comfortable, is aesthetically pleasing).

In the light of these considerations, the beauty of visual artefacts is not attributable to what could be loosely traced back to the Kantian notion of ‘*free beauty*,’ namely an ideal based on independence from concerns with functionality and classification (see Sibley, 1959; Schwyzer, 1963; Davies, 1997). The perception of free beauty does not entail classification of an object as belonging to a set of articles – either essentially defined or by family resemblance – as it is not concerned with *kind* and *function*. The source of free beauty is the pleasingness of a form that “rests on the free play of the imagination and the understanding” (Davies, 2006, p. 225). Neither the contrasting idea of ‘*dependent beauty*’ – which is equally of Kantian origin – seem to account for their specificity. Dependent beauty is the aesthetic property of an object that has a specific function – what Simon (1996) would call an artificial object. As Davies (2006, p. 235) argues, dependent beauty refers to an artefact that is “regarded as serving an aesthetic purpose subsidiary to its primary utilitarian function, and is then evaluated in terms not of its primary function but of this subsidiary one”. This separation between aesthetic quality and utilitarian purpose does not enable to theorise on the mutually supportive relationship between aesthetic and functional values that emerged from the case. In this sense, neither the concept of dependent beauty can account for the intersection of aesthetics and functionality depicted in figures 8 and 10 – as well as their components (i.e., the worm diagrams) – because, from this perspective, beauty would have the status of a mere epiphenomenon detached from functionality.

The impasse of these interpretations of the idea of beauty in the explanation of the aesthetic properties of visual artefacts can be addressed relying on the notion of ‘*functional beauty*’ (see Davies, 2006). A functionally beautiful artefact is one whose aesthetic properties enhance its capacity of fulfilling its primary practical and design function. In other words, the aesthetic and the functional both supervene on the same material design configuration of an artefact. In this sense, for a purposefully designed artefact that is characterised by aesthetic characteristics that are not merely incidental to its configuration, aesthetic evaluation is not an overall appraisal of how the artefact perform its functions, but rather a judgement on the input attributable to its aesthetic properties in performing its functions. In other words,

A functionally beautiful [*utilitarian object*] *u* (evaluated as a *u*, not in terms of secondary functions that are not central to its kind as such) is a *u* possessing aesthetic properties that contribute positively to its performing its intended principal function (Davies, 2006, p. 237).

In the light of these considerations, the idea of functional beauty provides an explicit theorisation of the status attributable to the aesthetic properties of data visualisation, as numerical and even beautiful pictures (Espeland & Stevens, 2008; Pollock & D’Adderio, 2012) without losing sight of their eminently functional and purposeful nature. The case has also shown that part of the influence of functionally beautiful artefacts lies in their capacity of attracting curiosity and attention. Wanting to know more about a visualisation emerged as an essential mechanism to engage interactors in the visual ethos (Kostelnick & Hassett, 2003; Kress, 2009) of the reporting function. Hence, it represents a precondition for making accounting visualisations actionable and influential in driving proactive behaviours. These concerns are further developed in the next section.

6.1.5. Visualisations to drive behaviour: Emphasising incompleteness and the visualisation of consequences

The principles and design criteria theorised thus far shed light on how reliance on multimodality and balance in the design of visualisations helps Crossrail's managers to engage with the multiplicity of the megaproject. The notion of visual relationality showed how patterns and forms could stimulate the formation of a sense of the 'bigger picture' in programme delivery by drawing novel associations. The ideals of optical consistency and functional beauty theorised respectively on the normalising and enabling properties of a shared visual language and the status of aesthetic attributes in the study of purposeful visual artefacts. A cross-cutting theme that emerges from the discussion is the designers' concern with the deployment of features that attract the interactors' attention, interest, and curiosity. As the participants frequently pointed out, making sure that people are attracted to visualisations is a critical factor in ensuring these artefacts become performable and influential. This section theorises on how artefacts can be designed to drive proactive behaviours reflecting on how they are adapted to the unfolding nature of project delivery (section 5.5.) and on the potentialities of the visualisations of consequences (section 5.6.).

The Closeout Dashboard (figure 5) was designed with the purpose of creating a visualisation that is fit for purpose in projects that are heading towards completion. The dashboard focuses on issues requiring attention to achieve sign-offs and timely completion. The need for this visualisation emerged from the realisation that once the core of the technical work has been successfully undertaken, projects were often losing momentum and completion tended to have a long tail. One of the visual strategies they adopted to tackle this challenge was to create a dashboard that deliberately over-emphasises the visibility of what is incomplete in a project. At about 80% completion, the worm diagram is replaced by a table that magnifies activities that are not finalised, drawing attention to the unfinished contracts instead of tracking performance with KPIs. Each contract completion status is expressed on a scale of zero to one hundred percent, without illustrating the overall completion score of the entire project. The remaining layout is modified consistently. The designers contended that emphasising

the incompleteness of the project is a strategy to persuade (see Jarzabkowski & Kaplan, 2015; Meyer et al., 2013) managers that much more work is required to reach completion. This is expected to drive behaviour in the closing out phase.

These considerations enable to further theorise on the issue of the incompleteness of accounting visualisations. Several studies have drawn attention to the potentially enabling role of incomplete measures in strengthening accounting systems in “not just communication of what is known but transformation of what is knowable” (March, 1987, p.165). Conceiving of accounting as an incomplete knowledge system with limited representational power, a growing body of research has shown ways managers cope with incompleteness (see Wouters & Wilderom, 2008; Dambrin & Robson, 2011). While these studies have shown that incompleteness may not necessarily impede the use of performance measures, the literature focused mainly on epistemological aspects of this issue (see Tinker, 1991; Carruthers, 1995) and little is known about how incompleteness can attract and drive behaviour. The evidence shows that designers strategically magnify the incompleteness of a project heading towards completion to mitigate the motivational issues that cause the signing off to have a long tail. In this sense, not only incompleteness can become a viable resource to enable managers to engage with a dashboard reflexively (Quattrone, 2017), but can also function as a trigger for managerial action. This goes beyond the general interdiscursive appeal of visualisations (Jordan et al., 2016) and points towards their capacity of driving behaviour in an agentic capacity. This design effort of triggering action by means of the visual design leverages on the rhetorical features of accounting visualisations, further detailing how the content of artefacts masks itself as information rather than argument.

The analysis of the performance assurance visualisations (section 5.6.) illustrates additional tactics that Crossrail’s reporting designers rely on to stimulate a proactive attitude towards accounting information. The participants contend that the deployment of the graphs in figure 6 was impactful in driving competitive and collaborative

behaviours among the contracting community. Coupling the analysis of the behaviour of CEO A with the visual analysis of figure 6 shows how data visualisations can be involved in bridging the gap between reporting and action. Drawing from behavioural psychology, Crossrail's designers constructed reporting products that, in their view, appear effective in driving behaviours. They did so by focusing on the idea of visualising consequences rather than antecedents (see Miltenberger, 2008). As explained in the case, an antecedent is an event that precedes a behaviour of interest for the designers, whereas the notion of consequence takes the form of a potential state of the world if an intended behaviour was to occur. As one of the designers eloquently explains relying on the metaphor of the behavioural impact of a signpost versus that of a speeding camera, nudging the interactor to reflect on personal consequences that may occur if he/she does or does not tackle an emergent situation— such as the poor performance of a contract in the case of CEO A – can have significant consequences. Figure 6 visualises a possible mental itinerary (Quattrone, 2015a) towards 'world-class performance'. Coupling such mental itinerary with what is de facto is a ranking system can trigger individual reasons for the appropriation of performance measures. These reasons for appropriation differ from the reactive power of rankings (Espeland & Sauder, 2007) or a rational approach to economic incentives. In fact, not only figure 6 of the performance assurance scoring framework worked as a *conscriptio device* (Henderson, 1991, 1999), namely an artefact that enlists group participation and is a receptacle for knowledge created and adjusted through group interaction aimed toward a common goal, but it also prompted "processes through which participants frame and reframe a situation [*which are*] an important part of understanding the making of meanings" (Boland, 1989, p. 602). Hence, being visualised in the graph was a precondition for engaging with other contractors and the sponsor team in the assurance process, but the contextual positioning of the anonymised dots created different understandings among the interactors involved in the process thanks to how they interpreted and appropriated the performance measures.

It is possible to argue that the visualisation in question is designed according to *teleological* criteria, namely as an artefact that not only offers a means to an end but

instead creates an end which prompts action (see Kornberger, 2013; Kornberger & Clegg, 2011). However, such a teleology (i.e., achieving the top-right blue area of ‘world-class performance’ in the graph) can offer triggers for managerial reflection and action that are individual and open to interpretation. The engagement with the visualisation in the competitive scenario of the performance assurance review was helpful in *imagining* future options (Comi & Whyte, 2017) for the programme. However, as the case shows, it also enabled the *testing* and *stabilisation* of solutions that affected both the dynamics of the assurance process (e.g., removing anonymity from the graph) and the programme delivery itself (i.e., the performance improvement traced back to the assurance process).

This illustrates how the visualisation of consequences can be implicated in making courses of action for the future realisable in a reflexive manner. This is not only a function of the “the relationship between the materiality (and the ‘now’) of visual artefacts and the immateriality (and ‘not-now’) of future” (Comi & Whyte, 2017, p. 24), but it shows how teleological visualisations can drive behaviours in a different, context-dependent fashion. That is made possible by the interpretive flexibility of the artefact (Orlikowski, 2004, 2007; Qu & Cooper, 2011), which enables doing and thinking otherwise. In this sense, the appropriation of the visualisation in interpretation implies that even artefacts that are designed for a specific function and relatively narrow purpose can prompt processes that are proactive and non-representational. The interpretive and meta-indexical flexibility of the visualisation support multiple readings by different parties. These readings are coupled with a design configuration that emphasises consequences that exceed the teleology of the artefact and the intention of its designers (see Busco & Quattrone, 2015). In this sense, the intention of the designers and their assumptions about the interactors emerge as non-deterministic figurations (Bjørn & Østerlund, 2014) with the objective of developing an understanding of the practices of future use.

6.2. Concluding remarks

This chapter developed analytically the central themes and issues that were outlined in the findings chapter. Specifically, the focus was on the theoretical development of the design criteria that make visual artefacts influential in megaproject delivery and in the identification of the principles that guided their practical construction. These principles and criteria aim to tackle the under-researched issues that relate to the design of accounting visualisations (Dambrin & Robson, 2011; Quattrone, 2017), the aesthetic and functional properties of numerical pictures (Espeland & Stevens, 2008; Pollock & D'Adderio, 2012), and the ambiguous rhetorical relationship between designers and users of visual artefacts (Qu & Cooper, 2011; Jordan et al., 2016). These concerns were shown to remain under-theorised, especially in connection with issues regarding the management of complex and unstable phenomena, such as the delivery of infrastructure megaprojects (Themsen & Skærbæk, 2018). To further develop the interest in the design of visual artefacts in the accounting literature, the discussion was guided by the mobilisations of the notions of affordances, visual conventions, and visual and aesthetic literacy. These design notions were deployed synergistically to guide the articulation of the design principles of discussion. The principles of multimodal balance and visual relationality show how visualisations can be designed to give presence to the megaproject's inherent multiplicity and emergent properties and to create novel associations that do not require the aspirational goals of referentiality and representational accuracy to be influential. The principle of optical consistency theorises how a visual language can normalise visual practices among designers and users, while at the same time creating the preconditions for recombination of visual features and their interpretations. The idea of functional beauty theorised on the analytical status of the aesthetic properties of purposeful visual artefacts. Lastly, the productive emphasis on incompleteness and visualisation of consequences provides insights into how visual artefacts can drive proactive behaviours and sheds light on how interactors appropriate performances measures. While the five design principles were presented as analytically distinct, they are to be understood as interacting with each other and not as mutually exclusive.

7. CONCLUSION

7.1. Introduction and overview

The delivery of megaprojects in general, and infrastructure construction programmes in particular, present significant technical as well as socio-political challenges in their conception, design, and delivery. This thesis argued that, due to their complexity and dynamic features, the management of such programmes can offer privileged opportunities to push the theoretical boundaries of current understandings of the roles of data visualisations – and visual artefacts more broadly – in the management of complex settings. More specifically, this study investigated the features that make visualisations influential and performable by focusing on the principles that the reporting designers rely on in the construction of dashboards and visualisations of KPIs. To explore these issues, this thesis focused on the reporting design practices in Crossrail's Programme Controls department. Theoretically, this exploration was guided by framework articulated on the basis of the design notions of affordances (Norman, 2013), visual conventions (Kostelnick & Hassett, 2003), and visual literacy (Messaris & Moriarty, 2005).

Answering to calls for research on the properties of numerical pictures (Espeland & Stevens, 2008), the visual nature of numbers (Qu & Cooper, 2011; Quattrone et al., 2013), and on issues in the practical construction of performance measurement technologies (Dambrin & Robson, 2011), the study offers three main contributions to interdisciplinary accounting, which are detailed in this chapter. The first contribution informs the accounting literature concerned with the design and practice of accounting visualisations (Quattrone, 2009, 2017; Pollock & D'Adderio, 2012; Jordan et al., 2016; Cooper et al., 2017), and the features that make them influential in supporting performance evaluation in complex settings. This study shows how designers construct organisational artefacts that enable productive engagement with the multiplicity and interconnectedness of the megaproject and theorises how such artefacts can support the creation of associations to tackle complexity and emergence.

The second contribution is to the recent interest on numerical pictures in accounting (Pollock & D’Adderio, 2012; Pollock & Campagnolo, 2015) and the exploration of the aesthetic dimension of organisational artefacts (Ewenstein & Whyte, 2007; Stigliani & Ravasi, 2018; Puyou & Quattrone, 2018). This thesis not only investigates the trade-offs between aesthetics and functionality in the design of visual artefacts but also proposes an application of the analytical notion of functional beauty to theorise on the status of aesthetic attributes. In this sense, building on the literature mentioned above, this thesis further explores how aesthetic features can augment the power and affordances of accounting visualisations.

Based on these insights, the third contribution of this study consists in the fact that it offers a design perspective to the study of the visual in accounting. This thesis, building on the existing research on the visual in accounting and complementing it with specific contributions from design theory, represents the first systematic articulation of a design framework in interdisciplinary accounting. The investigation of issues in the design of visualisations contributes to the understanding of how specific features of artefacts engage users and pre-form interaction in an interpretatively flexible (Orlikowski, 1992, 2007) and open-ended manner. Apart from the theoretical contributions, this concluding chapter also discusses the limitations of the thesis, its potential practical implications, and future research trajectories that could develop from this study.

7.2. Contributions

7.2.1. Contribution 1: Principles for the design and practice of visual artefacts

The first contribution this study makes is to the literature on the visual in accounting relates to the theorisation of the principles that make visualisations influential in the management of complex organisational phenomena. By detailing how designers deploy conventional features to anticipate the potential interaction possibilities of

visualisations, this study shows that accounting visualisations at Crossrail did not become influential only because of their simplicity (Pollock & Campagnolo, 2015), mediating and constitutive capacity (Pollock & D'Adderio, 2012), or interdiscursive appeal (Jordan et al., 2016). Instead, this study unpacks how specific design features were deployed to create a visibility that highlights the ever-unfolding ontology of the megaproject and supports the creation of unexpected associations among indicators to tackle its emergent properties. These considerations were coupled with a discussion of the importance of visual and aesthetic literacy (see Ewenstein & Whyte, 2007; Stigliani & Ravasi, 2018) as preconditions for engaging with organisational artefacts.

The design principles articulated in this thesis were developed on the basis of the relational ontology of sociomateriality (see Leonardi, 2011) and the notion of affordances (see Hutchby, 2001). On the one hand, affordances are relationships characterised by a purely potential mode of being that can only be actualised in interaction. On the other hand, sociomateriality stresses how the design configuration of artefacts shapes without determining interactions and interpretations. Accordingly, the building blocks of the design principles theorised in this thesis aim to retain and account for the importance of material and visual features of artefacts while avoiding reliance of 'technicist' assumptions (see Woolgar & Grint, 1997). In this sense, the contributions of this thesis are informed by and benefit from the inherent tensions of a framework that is concerned with sociomateriality and design, namely the theoretical interest in unpacking the complexity of sociomaterial practices while seeking to reduce the complexity of practice to enable the design of artefacts.

The principle of multimodal balance (section 6.1.1.) theorises how the orchestration of different modes (Kress, 2009) can support engagement with project delivery information. The harmonious visualisation of heterogeneous information that require different modes of presentation was shown to pre-form the engagement with the dashboard in a way that supports comprehensive evaluation of the performance indicators. The association of thematic delivery information to different modes

increases the prominence attributed to additional information categories, beyond a focus on value for money. Additionally, the reliance on multimodal design was shown to be illustrative of the project's complexity and facilitated the development of a visual inventory of concerns to be addressed in meetings (see Quattrone, 2009). The criterion of multimodal balances illustrates how reporting designers can capitalise on different modes of presentation to work against reductionist ideals of correspondence and engage interactors through diverse aesthetic forms and patterns.

The theorisation of this principle contributes to literature that has explored how information visualisation can help to increase the prominence evaluators assign to non-financial indicators (Lipe & Salterio, 2002; Cardinaels & van Veen-Dirks, 2010) by showing how non-hierarchical visualisation of KPIs and performance categories can afford negotiation among value criteria in decision-making. In so doing, specific visualisations – such as the worm diagram – were designed to prevent that one given financial value dimension would prevail univocally over others. This was achieved by means of their visual design, which aimed to discourage interactors from a reductionist overreliance on decontextualized indicators.

These contributions were further substantiated by the theorisation of the design principle of visual relationality (section 6.1.2.). Visual relationality is a way of visualising information that facilitates the creation of associations and meaningful connections within and among visual design features of dashboards and KPI visualisations. The theorisation of this principle was based on how the worm diagram can afford quick categorisation of how different projects are performing, highlighting oddities and similarities among visual patterns. The visual relationality of the diagram showed how these visualisations can, on the one hand, enable the creation of meaningful associations among the diverse projects that constitute the programme and, on the other hand, explicate the interrelations between different KPIs in the same project. Artefacts designed according to this principle highlight the megaproject's heterogeneity and are not primarily concerned with referentiality and representational

accuracy (see Jordan et al., 2016; Kornberger et al., 2017). Combined, multimodal balance and visual relationality show how it is possible to visualise complexity and emergence in non-correspondence-based capacity and illustrate design features that make accounting visualisations performable.

Building of these insights, the discussion on the productive emphasis on incompleteness and the visualisation of consequences (section 6.1.5.) contributes to the understanding of how visualisations can be designed to drive proactive behaviours. The discussion of this principles showed how artefacts that are incomplete by design (Garud et al., 2008; Quattrone, 2017) could work as triggers for managerial reflection and action. In the exploration of the design features of the Closeout Dashboard, not only the design choice of over-emphasising the visibility of what is incomplete is an instantiation of the rhetorical work and persuasive power of visualisations, but also illustrates how the incompleteness material features of visual artefacts can have proactive and generative effects. Similarly, the idea of visualising what – in behavioural terms – are called consequences rather than antecedents (Miltenberger, 2008) shows how artefacts that are designed for a specific function can prompt processes that are proactive and non-representational. In this sense, this criterion illustrated that ‘teleological’ visualisations (Kornberger, 2013; Comi & Whyte, 2017) could drive behaviours in a context-dependent manner by triggering reasons for appropriation that go beyond a rationalistic approach to incentives and the alleged representational value of visual artefacts.

7.2.2. Contribution 2: Designing numerical pictures

The second contribution of this study is to the literature on numerical pictures in accounting (Espeland & Stevens, 2008; Pollock & D’Adderio, 2012; Pollock & Campagnolo, 2015) and the emerging interest on aesthetic properties of artefacts in organisation studies (Ewenstein & Whyte, 2007, 2009; Stigliani & Ravasi, 2018; Puyou & Quattrone, 2018). Specifically, this project theorises on how aesthetics and

functionality inform the design of numerical pictures that are not only compelling and fit for purpose, but also beautiful. Building on works that identified the existence of an aesthetic dimension that is inherent to accounting (Thompson, 1998; Suzuki, 2003b), this study details how aesthetic design concerns are influential in making visualisations performable. Concepts such as beauty, balance, simplicity, and dynamism (see Pollock & Campagnolo, 2015; Stigliani & Ravasi, 2018) emerged not only as pertinent aesthetic phenomena but also as specifications that can augment the power of accounting visualisations and what they afford in interaction.

Reporting designers in the case often referred to the importance of aesthetic values in the construction of visualisations, illustrating the existence of tensions around how to reconcile functional information requirements with the beauty of their form. One important aspect that emerged from the findings is that high-order visualisations (e.g., the programme dashboard) that aim to create a synthetic big picture of the programme (Boland et al., 2008) tend to comply more easily with aesthetic notions (see Tufte, 1983). The reporting designers stated that, in achieving a final design for a ‘big picture’ visualisation, aesthetics acquires more importance than exactness, precision, and other representational ideals. That is because a fundamental reason behind the influence of these artefacts is that they attract attention and curiosity by means of their visual features.

This study unpacked the status of such aesthetic dimension drawing from and expanding the idea of functional beauty (section 6.1.4.). A functionally beautiful artefact is one whose aesthetic properties contribute positively to it performing its intended principal function (Davies, 2006). The idea of functional beauty complements existing literature on numerical pictures (Espeland & Stevens, 2008; Pollock & D’Adderio, 2012) and on the aesthetic values in design processes (Ewenstein & Whyte, 2007, 2009; Stigliani & Ravasi, 2018) by articulating in an analytical manner the meaning of aesthetic attributes and their pragmatic importance in guiding design and interaction.

Accordingly, the theorisation of aesthetic aspects of visualisations provided in this thesis contributes to and further unpacks Espeland and Stevens' (2008) contention that the aesthetic aspects of numerical pictures are essential in ensuring that numbers can be practiced in a variety of social and organisational domains. The theorisation of the notion of functional beauty, coupled with empirical insights from the case study, shows that aesthetic attributes are not a mere epiphenomenon of quantitative measures and performance indicators, but an intrinsic property that directly influences how numerical pictures are practiced and enacted in context. In this sense, this thesis expands the understanding of how aesthetic and material features of visualisations shape and influence interactional processes by exploring some of the micro-processes through which the 'aesthetics of quantification' (Espeland & Stevens, 2008) – through numerical pictures – comes to matter in complex organizational settings.

Moreover, this research contributes to this stream of studies by theorising the importance of visual conventions (Kostelnick & Hassett, 2003) in the design and practice of organisational artefacts. Since the presence of design features in visualisations is not sufficient to ensure and explain effective interaction in context (Norman, 2013), this study relied on visual conventions to clarify how designers deploy forms in the hope that specific designs will convey the intended interactional possibilities. In this sense, this thesis tackles a theoretical issue that was tangentially identified by Pollock & D'Adderio (2012) and others (Hoskin & Macve, 1986; Espeland & Stevens, 2008; Quattrone, 2017). Namely, it further theorises the importance of conventional elements in the construction of data visualisations. Visual conventions provide the thread that connects our perceptual experiences, by constructing the underlying structure that prevents the design from dissolving into rhetorical anarchy.

The theorisation of visual conventions, articulated through the principle of optical consistency (section 6.1.3.), contributes to a more nuanced understanding of the

enabling and constraining aspects of visualisations (see Latour, 1986; Qu & Cooper, 2011; Pollock & D'Adderio, 2012; Busco & Quattrone, 2015; Jordan et al., 2016). Optical consistency shows how a visual language can normalise visual practices among both designers and users, while at the same time creating the preconditions for innovation and recombination of visual features and their interpretations. These concerns were unpacked in relation to their impact on the 'design mode' and 'use mode' (Orlikowski, 1992) of organisational artefacts. In the 'use mode', optical consistency ensures that distinct interactional possibilities are more likely to emerge in the engagement with an artefact thanks to the conventional currency of its features. In the 'design mode', the reliance on of common visual codes constrains the creative capacity in the conception and realisation of organisational artefacts. In the light of these considerations, the principle of optical consistency further clarifies how a visual language plays essential compositional and rhetorical (Quattrone, 2009) as well as persuasive (Davison, 2015) roles in orchestrating interaction with accounting and project management information for different audiences.

7.2.3. Contribution 3: A design perspective on accounting visualisations in megaproject management

The study's third contribution is to offer a design perspective on the study of accounting visualisations. The meaning of 'design perspective' here is twofold; this study is both (a) empirically focused on how reporting designers construct data visualisations to support the delivery of a megaproject, and (b) it is based on a framework articulated based on concepts and notions borrowed from the research domain of design theory. With its theoretical focus on the criteria according to which dashboards are constructed, the study foregrounds the importance of focusing on the design side of the realisation of visualisations, highlighting how designers induce the 'hoped for' interactional possibilities and emphasising their agency in practices of future use.

As a discipline, design is concerned with the deliberate creation of artefacts within a tradition of practice, investigating what enables interaction and considering what attracts attention and engages the users. Accordingly, unlike most of the extant literature on accounting visualisations, this study's focus does not lie on how visual artefacts unfold in potentially novel and unexpected ways through their use (e.g., Qu & Cooper, 2011; Busco & Quattrone, 2015), but on how designers envision interaction and exert influence over practices of future use. In so doing, the study answers calls for research on the investigation of the visual nature of numbers (Qu & Cooper, 2011; Quattrone et al., 2013), on issues in the practical construction of dashboards and performance measurement visualisations (Dambrin & Robson, 2011), and on the properties of forms of visualisation that draw from ideals of aesthetics and functionality (Espeland & Stevens, 2008; Pollock & D'Adderio, 2012).

The development of a design framework that foregrounds the importance of the designers' agency in shaping interactions with artefacts and the construction of visibilities in complex organisational settings challenges the interpretation of the roles artefacts in visual research in accounting. In fact, the theoretical position developed in this thesis aims to tackle issues and concerns that have been backgrounded by the inscriptions literature on the visual (e.g., Busco & Quattrone, 2015; Thomsen & Skaerbaek, 2018) and hermeneutic approaches to the study of accounting technologies (e.g., Boland, 1989). By putting at the forefront of the analysis the design features and sociomaterial arrangements that make visualisations influential, this thesis calls for further exploration of how the technical and design affordances of artefacts are essential determinants of interactive processes, which are attributes that plainly matter, beyond strictly situational considerations. In this sense, drawing from the notion of affordances and the relational ontology of sociomateriality, this approach emphasises the importance of design features and criteria in shaping the construction of visibilities, understandings, and interpretations in context.

The articulation of a framework (chapter 3) based on the interrelation of the design notions of affordances (Norman, 2013), visual conventions (Kostelnick & Hassett, 2003) and visual literacy (Messaris & Moriarty, 2005) contributes to academic understanding of how the material configuration of artefacts and visualisations engages users in a flexible and open-ended manner. The articulation of these theoretical lenses was applied to a setting and a case that were argued to present paradigmatic features for a series of reasons. Not only is the construction of infrastructure megaprojects complex, dynamic, and risky but is also characterised by non-standard technologies and ambiguous interfaces (Flyvbjerg, 2014). Additionally, megaprojects as temporary project structures have an always unfolding ontology that can cause the occurrence of unexpected emergent properties. In turn, representing these dynamic phenomena is exceptionally complicated, and poorly designed artefacts and strategy tools can have dramatic consequences regarding performance and benefits realisation. Additionally, the management of megaprojects is a setting characterised by a significant reliance on visual artefacts associated with the engineering, project management, and accounting professions (Henderson, 1999). For these reasons, megaprojects are ideal settings to explore how information visualisations become influential and performable in complex settings (Whyte et al., 2007; Quattrone, 2017; Thomsen & Skærbæk, 2018). Hence, the investigation of how reporting designers, controls engineers, and accountants visualise information to support project delivery contributes to addressing Hopwood's (2005) contention that the operation of accounting in temporary project structures and megaprojects remains poorly understood, despite the significant potentialities for development it yields.

7.3. Limitations, implications and future research

7.3.1. Limitations

As discussed in the methodology section, non-participant observation played a minor role in the data collection process. The reasons behind this issue related to time constraints and research funding, privacy and confidentiality concerns, as well as the maturity of Crossrail during the period of the investigation. Given that the fieldwork

was partly self-funded, financial constraints would have complicated a long-term ethnographic study. When the data collection for this research project started (January 2017), Crossrail was already more than 80% complete. In this sense, being the programme already in the back-end of delivery, its management and accounting practices were already firmly consolidated and affected by a significant element of path-dependency that was further strengthened by management continuity over more than eight years. While the study gained important insights regarding the implementation of recently introduced visual templates (e.g., the Closeout Dashboard), the accounts of the implementation of other visualisations relied on second-hand interpretations based on the memory of participants that could not be directly supported by observation. Additionally, the investment and perceived importance of the development of new designs for the reports was likely decreasing in this phase of programme delivery. Because of the same reasons, the programme's maturity level implied an increased reluctance of the organisation in incorporating potential insights from this research in its current practices. Given the design culture of the organisation, if the programme happened to be in different phase of realisation, there would have likely been opportunities for interventionist and even experimental research.

Even though the organisation offered generous access to people, resources, reports, and archival information, for understandable reasons I was not given permission to conduct non-participant observation of senior management meetings (e.g., Board Meetings) in which, according to the accounts gathered, visualisations play a crucial role. In this sense, if I was present in such meetings I could have likely gained deeper and more fine-grain insights into the practice of visual artefacts and how their design pre-forms interactions and conversations. Additionally, confidentiality concerns affected data collection in relation to the sponsor organisations (i.e., DfT and TfL). Negotiating non-disclosure agreements within a feasible time horizon proved to be difficult and requesting clearance of the findings from two additional parties would have compromised the viability of the study and potentially caused concerns regarding the divulgation and publication of the findings. Hence, all the conversations with the sponsors were not recorded, had 'informal' status, and offered limited insights.

Conducting additional data collection in relation to the sponsors' perspective could have offered a broader and richer perspective on the issues at hand. In the light of these considerations, conducting more hours of observation and developing a study that relied more extensively on ethnographic methodologies could have offered a more comprehensive visibility on the organisation and its sociomaterial practices. This, however, was not possible because of the constraints outlined above and timeline of the PhD project.

7.3.2. Implications

This study's discussion and contribution sections have highlighted the contributions to the study of visualisations in accounting and organisation theory. However, apart from its theoretical contributions, the study has practical implications. Most notably, a significant practical implication is for people in charge of reporting and dashboard design in complex organisational settings. The thesis has provided novel and thorough insights into the criteria that make visualisations powerful in shaping decision-making and interaction in megaproject management. Each of the principles theorised – multimodal balance, visual relationality, optical consistency, functional beauty, and the visualisation of consequences and incompleteness – contributes to the understanding of factors that may aid or hinder the design and practice of visual artefacts to tackle complexity and emergence in practice.

Additionally, the design framework of this study (section 3) was deliberately articulated in a way that would retain the purposeful and substantive dimension that is inherent to design theory and practice (see Simon, 1996; Arnheim, 1993). The concepts of affordances, visual conventions, and visual literacy were selected as the core lenses to explore Crossrail's design work also in the light of their potential validity in informing practitioners. Each of the notions above and their interplay, despite not being reductionist or positivistic in nature (Hutcheon, 2001), can also be interpreted as guiding criteria for the practical construction of artefacts (Bjørn & Østerlund, 2014).

Even though the principles theorised in this study are not to be understood as prescriptive in nature, they could easily be implemented in the practical design of visual artefacts in different settings. Beyond the specificity of the focus on megaproject management, the conclusions that can be inferred from the study are of relevance for the design of strategy tools and reporting products more broadly.

This thesis can, in fact, be read as highlighting the importance of investing in the development of visual culture and literacy in an organisation. It illustrates the potential that the design of artefacts has in identifying approaches to cope with dynamism and change and the diagnosis of emergent issues. This study also offers precise criteria that may induce people to want to engage with visual artefacts, to drive proactive behaviour. This was exemplified by the tactics of magnifying what is incomplete in a project and visualising consequences as opposed to antecedents. Additionally, beyond the academic interest on aesthetic phenomena in organisations, this thesis showed that paying attention to the perceived beauty of dashboards and reports is an important aspect in the practice of visualisations. In this sense, the idea of functional beauty can be interpreted as a criterion to assess if aesthetic design contributes to functionality in the creation of new visual artefacts. The notions of multimodal balance and visual relationality draw attention to how it is possible to orchestrate different modes to visualise complexity and how specific features can prompt the development of associations and contribute to breaking a silos mentality in complex programmes.

7.3.3. Future research

A central question that emerges from the study of the reporting design practices in Crossrail is the extent to which the five design principles might have similar enabling and constraining properties in different organisational contexts. Future research might explore visual practices in megaprojects that are less mature than Crossrail, to investigate if programmes in different delivery phases, and especially at the front-end phase, have substantially different information design requirements. Additionally, an exploration of similar concerns in smaller-scale projects could provide important

research insights. As mentioned earlier, Crossrail is an exceptional programme not only about its size, ambition, and performance but also in relation to the unusual feature of having management continuity for its entire duration. In this sense, these factors influenced its visual practices. Because of these reasons, focusing on smaller megaprojects with a shorter delivery cycle could offer valuable insights and lead to different research contributions.

Similar research questions could be meaningfully explored in contexts that differ from infrastructure construction programmes. Megaprojects are defined by the high degrees of dynamism and complexity, and in such programmes, the stakes are high because planning and delivery mistakes can have calamitous consequences. While the design principles can offer important insights for most complex organisations in relation to the capacity visualising information, the principles appear to be particularly relevant for organisations that are expected to perform in challenging, high-performance environments. The contributions of this study do not apply to every organisation to the same extent. However, there is potential in the exploration of similar issues in settings that do not share these extreme features. In this sense, future research could tackle similar issues in public sector organisations and governmental departments that are characterised by significant information requirements and reporting cycles, in the delivery of ‘big science’ programmes, and in the context of more conventional corporations. Accordingly, it would be interesting to investigate if different or additional principles are needed to account for the roles of visualisation in those settings or even to replace the criteria offered by this study.

Future research might also explore issues of the design of visualisations that rely more heavily on digital media. In Crossrail, even though most of the reports were also available in digital format, the focus and interaction revolved more evidently around printed out versions and physical artefacts. In this sense, exploring the effects that digital interfaces have in shaping individual and group-level interaction could provide innovative insights that could be especially interesting given the increased reliance on

digital technologies in the workplace (Murray, 2012; Whyte, 2013). Since accounting practices are becoming increasingly reliant on automated software and digital technologies (Quattrone, 2016), it is possible to argue that issues of human-computer interaction and interface design are going to become increasingly central for accounting practices. Hence, explorations of the design aspects accounting and ERP software could offer viable and interesting research insight that would contribute the research agenda set out by this thesis.

Along similar lines of enquiry, cognitive aspects of interactions with visual artefacts in organisational processes such as collective sense-making and interpretation would enable to connect visual design with the outcomes of interactions. This potential focus on the cognitive work of visual artefacts (see Stafford, 2007; Clark, 1993, 2008) could also be explored relying on interventionist and experimental methodologies, which in turn would enable empirical testing of design criteria to show the effect of visualisations in decision-making (see Cardinaels, 2008).

7.4. Concluding remarks

This final chapter has discussed the thesis' objectives, its contributions, and outlined limitations, practical implications and possible future research trajectories. This chapter unpacked the contributions of the five design principles theorised in the discussion section. By developing the principles of multimodal balance, visual relationality, optical consistency, functional beauty, the productive emphasis on incompleteness and the visualisation of consequences, the study has investigated how accounting visualisations become influential in the delivery of Europe's biggest infrastructure megaproject. In doing so, this chapters showed how this thesis offers three different contributions.

Firstly, it contributed the accounting literature concerned with the roles and functions of visual artefacts (e.g., dashboards) in the management of complex organisational

settings. Specifically, the thesis identified criteria according to which reporting designers visualise the always-unfolding ontology of megaprojects in a non-reductionist capacity. It also theorised how such artefacts could prompt the development of mental associations to tackle complexity and emergence, and how they are implicated in driving reflection and proactive behaviours. Secondly, the thesis has advanced the study of the aesthetic dimension of visualisations in a twofold manner. It has theorised the analytical status of the aesthetic attributes through the notion of functional beauty and has expanded the understanding of the enabling and constraining aspects of aesthetics in the practice of visual artefacts. Thirdly, this study offered the first systematic articulation of a design framework in interdisciplinary accounting. Relying on a design perspective, the thesis has theorised on the importance of visual practices in megaproject management and has contributed to better understanding of the inherently ambiguous rhetorical relationship between designers and users of organisational artefacts.

As discussed in the above, this thesis' relevance goes beyond academic debates and contributions, and could also offer real insights for reporting designers and managers involved in the management of complex organisational settings, beyond the specificities of megaproject delivery. Although the principles theorised here are not prescriptive in nature, they could easily lend themselves as practical criteria that could inspire the practical construction of visual artefacts in a variety of organisational contexts. However, it is important to emphasise that these principles are not to be understood in isolation, and their effectiveness in Crossrail related to their simultaneous interplay, in connection with the visual and aesthetic literacy of key managers and reporting designers in the organisation, and the visual culture of the Programme Controls department more broadly.

This thesis has sought to make a case for the importance of focusing on core visual and aesthetic features that are inherent to accounting technologies. The value-laden visibilities that such artefacts create on organisational matters can have a variety of

powerful generative, mediating, enabling, and constraining effects that may significantly impact the delivery of complex programmes. Arguably, given the increasingly important roles of digital technologies in management and accounting practices, the design of visualisations and interfaces is going to become increasingly consequential in the near future. Developing and fostering visual literacy and the capacity of engaging with advanced visual displays of information in organisations will likely become a matter of survival in the workplace. The design of visual artefacts that stimulate processes of reflection, interpretation, and interrogation of vast amounts of information will be of utmost importance to tackle future management challenges in a world increasingly characterised by information overload, unpredictability, and emergence.

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