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# Resolving Conflict in Problem-Solving:

# Systems of Artefacts in the Development of New Routines

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**ABSTRACT**: This paper argues that, in order to understand the development process of new routines, we have to look at the emergence of systems of artefacts rather than at individual artefacts in isolation. The paper proposes a typology of artefacts understood as material objects that are the product of human activity and analyses their interactions in the case of an integrated engineering design consultancy engaged in the effort of developing a new bidding routine. The evidence from the case study shows that agents reinforce and extend the patterns of action that individual artefacts support by bundling different types of artefacts, and that in so doing, they extend the reach and influence of the community to which they belong. This study shows that the problem-solving and truce aspects of routines are worked out in the design of these systems of artefacts.

# INTRODUCTION

Research in the structuration and pragmatic traditions has changed our understanding of routines, showing that the observable, repetitive patterns of behaviour in organizations are the effortful accomplishment of mindful individuals, rather than the mindless execution of fixed responses to given stimuli (Feldman, 2000, 2003; Feldman and Pentland, 2003; Howard-Grenville, 2005; Salvato, 2009; Rerup and Feldman, 2011; Turner and Fern, this issue). This work sheds light on the role of agency, or the capacity of individuals to form and achieve their goals (Giddens, 1984; Leonardi, 2011), in how routines persist and change over time. However, we know little about how new or radically different routines are developed (cf. Zollo and Winter, 2002; Rerup and Feldman, 2011), the role individual agency plays in their development (Boisot and Li, 2005; Felin and Foss, 2005) or the part played by the development process in the translation of firm experience into capabilities (Heimeriks, Duysters and Vanhaverbeke, 2007). These are central issues that need to be addressed if, as much of the strategic and organizational literature holds, differences in routines drive different performance across firms.

Structuration and pragmatic approaches suggest that to understand the development of new routines, we need to move beyond a disembodied view of the individual's actions and cognitions to examine how agency occurs and is shaped by the artefactual context in which individuals operate. The role of artefacts - the material objects produced by human activity (cf. Gagliardi, 1992; Rafaeli and Pratt, 2006) - in routines is controversial. Some authors emphasize their role in patterning organizational behaviour by giving a voice to some actors and not others (e.g., Cacciatori, 2008; Kaplan, 2011) and facilitating certain courses of action while making others more difficult (Henderson, 1991; D'Adderio, 2003, 2008). Others question the wisdom of relying on the design of artefacts in order to produce change in organizational processes (Pentland and Feldman, 2008).

I take a step towards reconciling these positions arguing that the relationship between artefacts and routinization is clearer if we focus the analysis on systems of heterogeneous, interacting artefacts rather than individual artefacts in isolation. Not all artefacts influence behaviour in the same way or through the

same mechanisms. This paper develops a framework that classifies artefacts along two dimensions. The first considers whether or not the artefact embodies a formal representation of knowledge, such as text, drawings or mathematical formulas. The second classifies them on the basis of whether they are generic, or specific to occupations. I discuss the efforts of an engineering design firm to redesign its bidding process in response to the emergence of new integrated procurement routes. The in-depth case study focuses on an Excel Workbook used to estimate costs over the entire life cycle of a building (including design, construction, maintenance and services). It describes the evolution of the workbook in relation to both the bidding routine it was meant to support and artefacts, such as drawings and procedures, that operate within that routine. I show how agents purposefully craft how an occupation-specific artefact (such as the Excel Workbook used to estimate costs) interacts with generic artefacts (such as bidding procedures) and other occupation-specific artefacts (such as technical drawings). By bundling different types of artefacts, agents reinforce and extend the patterns of action that each supports and extend the influence of their particular communities to other occupational groups within the organization. Analysis of the systems of artefacts reveals the interplay between different organizational processes - aimed at solving problems and aimed at establishing positions of influence and power.

The task of developing an Excel Workbook may seem trivial. However, in the case study firm it turned out to be otherwise, and the company was only marginally successful in restructuring its bidding process. I analyse the areas of partial success and failure showing that it is the interactions among heterogeneous artefacts (as opposed to the individual features of specific artefacts), that explains their role in the process through which individual choices are (or are not) institutionalized into organizational routines.

The paper is organized as follows. Section 2 develops an artefacts typology based on the literature on the role of artefacts in organizations. Sections 3 and 4 describe the empirical setting and the method. Section 5 presents the empirical evidence from the case study. Section 6 discusses the implications of the case and develops a model for the development of new routines which highlights the role of artefacts in mediating individual agency. Section 7 presents the conclusions.

## MICRO-FOUNDING ROUTINES ON ARTEFACTS

Debate on the microfoundations of routines (Felin and Foss, 2005, 2009; Hodgson, 2008; Salvato and Rerup, 2011) is part of a larger and long-standing debate on the prominence of individual agency or social structure in determining individuals' behaviour (e.g., Reed 2003). In this larger debate, structuration theory (Giddens, 1984) seeks to integrate agency and structure, arguing that structure is 'dual', that is, that social structure both shapes and is constituted by people's practices, so that individuals can and do purposefully change it. Structuration theory and closely related pragmatic approaches (Bourdieu, 1990) connect agency and structure and enable the development of solid microfoundations for the notion of routines. Several studies investigate how individuals 'knowledgeably' use the material and immaterial resources that constitute their practice, to maintain and change routines (e.g., D'Adderio, 2008; Howard-Grenville, 2005; Pentland and Rueter, 1994; Rerup and Feldman, 2011; Salvato, 2009; Turner and Fern, this issue). However, artefacts are rarely the main focus of analysis, and there is no comprehensive framework that explains how the material context of work matters for routines. At the same time, a growing body of research, particularly in the pragmatic tradition, has highlighted how human activity takes place through and is mediated by manmade material objects (e.g., Orlikowski, 1992, 2007).

I propose a two-dimensional typology of artefacts that maps onto the 'cognitive' and 'truce' aspects of routines (Nelson and Winter, 1982). It builds primarily on studies in the structuration and pragmatic traditions, but also incorporates findings from work on knowledge codification (e.g., Cowan, David and Foray, 2000; Steinmueller, 2000) and the symbolic value of artefacts (e.g., Gagliardi, 1992). The first dimension of the typology distinguishes between 'speaking' and 'silent' artefacts. The former contain formal representations of knowledge in verbal, mathematical or visual form. Since the formal representation of knowledge is fundamental to its manipulation, this dimension facilitates examination of the role of artefacts in the problem-solving, cognitive aspect of routines. The second dimension distinguishes between generic artefacts and those associated with specific occupations. The trend towards multitechnology products and greater specialization (e.g., Granstrand, Patel and Pavitt, 1997) implies an

increasing need for collaboration among specialists. Such collaborations can be problematic due to different ways of framing problems and representing knowledge (e.g., Dearborn and Simon, 1958; Dougherty,1992). Beyond these cognitive difficulties, occupations struggle for dominance, as extensively documented in the sociology of work and professions, and some studies have begun to investigate how artefacts contribute to this struggle (Bechky, 2003a). Classifying artefacts as generic or occupation specific enables analysis of their role in organizational conflict. Figure 1 provides a classification of artefacts based on these two dimensions; the case study shows how these two dimensions interact in the process of routine development.

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INSERT FIGURE 1 ABOUT HERE

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## Speaking artefacts

Speaking artefacts contain textual or visual representations of knowledge. They include procedures, manuals, reports, technical drawings and virtual prototypes – which last typically combine visual and textual information in complex ways. Formal representations facilitate the manipulation of knowledge, and speaking artefacts (e.g., virtual prototypes) afford easier manipulation of the knowledge they embody than do 'silent' artefacts (e.g., clay models). The manipulation of formal representations of knowledge is generative in the sense that it contributes to the creation of new knowledge (Simon, 1996; Foray and Steinmueller, 2003). The clearest example of this is in physics, where the manipulation of mathematical representations of the world led to the 'discovery' of phenomena whose experimental demonstration followed much later. In the context of organizations, the introduction of virtual modelling and simulation has enabled faster development of better products (Thomke, 1998; Nightingale, 2000). Two types of speaking artefacts have attracted particular attention: *product* representations, which include sketches, technical drawings and their digitalized counterparts, virtual prototypes; and *process* representations,

which include procedures and checklists. I examine these two types of speaking artefacts separately because process representations have more direct and more studied relationships with routines.

Much of the recent work on the material aspects of organizing focuses on representations of products and studies their role in mediating the joint problem-solving activities of different specialists. Product representations are examined in their function as 'boundary objects'. Boundary objects (Star and Griesemer, 1989; Carlile, 2002, 2004) are artefacts that can adapt to different contexts while simultaneously maintaining a common identity across contexts. By combing the flexibility to adapt to the needs of specific groups in 'local' use with rigidity to maintain consistency across sites for 'global' use, boundary objects enable groups with different practices and ways of framing problems to collaborate, while preserving the advantages of specialization.[i]

While studies of boundary objects are aimed at investigating collaborative problem-solving rather than routines, they show that product representations influence the organizational processes they support. What is represented and how, determines the way the problem is constructed, and who will have a voice in solving it and at what stage (D'Adderio, 2003; Cacciatori, 2008; Kaplan, 2011; Orlikowski, 1992), thereby providing 'paths of least resistance' that funnel organizational action (D'Adderio, 2003). The strength of this funnelling is a function of the way in which knowledge is represented. Effective problem-solving across different occupational groups requires flexible representations that can be adapted to the needs of different specialists in local use, that are easy to manipulate and that evolve in parallel with the problem-solving activity (Bowker and Star, 1999; Carlile, 2004). In this respect, Ewenstein and Whyte (2009) building on Knorr-Cetina (1999) prefer to distinguish between evolving 'epistemic objects' that leave opportunity in their structure for what is not yet known, rather than (static) 'boundary objects'. Alternatively, if the artefact per se is not sufficiently flexible, there must be scope for each occupational group to develop 'translating' mechanisms, that make it possible to go back and forth between different local, group-specific representations and global representations (D'Adderio, 2001).

On the contrary, rigid representations are required to make distributed action converge to specific patterns. For instance, the rigidity of representations in technical drawings compared to sketches allows

the former to support the coordination of production activities between design and manufacturing, making them work as 'conscription devices' that organize distributed activities (Henderson, 1991). Organization members often need to choose between changing the artefact or changing their behaviour: the choice tends to depend on the modifiability of the artefact (Leonardi, 2011). The flexibility that makes a product representation effective for problem-solving often makes it ineffective for funnelling action towards desired sequences, and vice versa (Henderson, 1991). The differential ability of product representations to funnel action combined with the patterning ability of artefacts being limited to the actions they support (Pentland and Feldman, 2008), points to the importance of looking beyond individual artefacts to understand their role in routinization.

The role of artefacts in routines has been investigated more extensively in relation to representations of processes, and especially procedures. Procedures are representations of an intended (by some organizational actor) routine and, therefore, are a reification of the ostensive dimension of routines (Feldman and Pentland, 2003). The relationship between procedures as representation of routines, and the routine as performed is never one to one because procedures can never fully specify action (Pentland and Feldman, 2005). Procedures are better understood as one of the resources that individuals bring to a situation in order to deal with it (Suchman, 1987; Turner and Rindova, 2011). D'Adderio (2008) shows that software embedded procedures and actual behaviour go through cycles of convergence and divergence, with procedures and behaviour alternately taking the lead. Again, research on the importance of the type of representation has produced interesting and counterintuitive results. Detailed representations of processes may be used to increase accountability and constrain the actions of actors. However, they also enable the actors to understand the purpose and functioning of the system and, therefore, to devise solutions to the problems they encounter, and can so favour deviation from a rigid pattern (Adler and Borys, 1996; Narduzzo, Rocco and Warglien, 2000).

## Silent artefacts

Silent artefacts, which include items such as furniture, clothing and tools - ranging from hammers to stethoscopes - do not contain textual or visual representations of knowledge. They constitute the majority of the artefacts in our world. They embody and make knowledge available for use, most notably in tools and equipment, but in ways that are less directly manipulable than is possible with speaking artefacts. Their role in distributed problem solving is important, but more limited. Bechky (2003b) argues that, in the context of inter-occupational problem-solving, silent artefacts work primarily by providing *grounding*, that is, by providing a way of cross checking meanings across occupations. Again in the context of inter-occupational collaboration, research suggests that the primary role of silent artefacts may be that of being the objective of the collaboration, as in the case of the development of a new product, in this way acting a motivators of collaboration (Nicolini, Menger and Swan, 2011).

Silent artefacts embody and make available knowledge about how to carry out a task through their *action affordances*, that is, the actions suggested by their shape. For instance, a handle shape can suggest a lifting movement (a jug handle) or a downward pressure (a door handle). Evidence from psychology suggests that rather than reasoning about artefacts, we associate with them experience-based action possibilities (Cohen, 2010). These associations guide most of our use of everyday objects and are at the centre of a vast field of design (e.g. Norman, 1988) and information systems (Leonardi, 2011). In suggesting the actions required to achieve a goal through their action affordances, silent artefacts make certain courses of action more likely than others, thereby contributing to patterned behaviour. Bapuji and Saeed (this issue) provide empirical evidence of this by showing that introducing silent artefacts with more direct affordances to desired actions considerably strengthens the stability of routines.

## Artefacts specific to occupations

Artefacts specific to occupations constitute the 'tools of the trade' of an occupation or a group of closely related occupations. Examples of specific silent artefacts include the stethoscope used by medical practitioners, the scalpel used by surgeons and the compass used by engineers. Examples of speaking

artefacts specific to occupations include accounts ledgers, and the technical drawings used by engineers and architects. The association between these artefacts and specific occupations is not necessarily one to one: both artefacts and occupations evolve. Artefacts may be developed for a specific occupation and spread to similar occupations. Many occupations are becoming increasingly specialized, with the result that occupations that 'branch out' share some of the tools of the originating occupation. Nevertheless, these artefacts remain sufficiently specific and essential in an instrumental sense (e.g., the accountant cannot work without a ledger), that they often represent it symbolically (cf. Fiol and O'Connor, 2006; Vilnai-Yavets and Rafaeli, 2006).

If we look at artefacts as the essential tools of an occupation, their potential to generate conflict becomes apparent. Studies of technical change document that, by embodying and blackboxing knowledge, new equipment can move the locus of knowledge control, or make the knowledge held by certain groups obsolete or irrelevant, sparking conflict in the process. A prominent example of this is the conflict that ensued between management and workers as a consequence of the innovations in technique and equipment introduced by Taylor and Ford. In one of the few studies that investigate the 'truce' aspect of routines, Coriat and Dosi (1998) show the different routines that emerged in the west and in Japan, in order to achieve truce. Similarly, Barley's (1986) famous study of the introduction of computed tomography on the social organization of hospitals and Black et al.'s (2004) extension of that study using a simulation model, show how new, occupationally specific artefacts produced by technical change can alter divisions of labour and threaten established authority and status systems. Knowledge codification, which changes who can use knowledge and how, is often an important part of the process (Bowker and Star, 1999; D'Adderio, 2003; Lazaric and Denise, 2005; Lazaric, Mangolte and Massué, 2003) and suggest that speaking artefacts that are occupation specific are likely to play a critical role in both problem solving and conflict.

Work on professions is exploring the role of occupation-specific artefacts not linked to technological innovation in interoccupational conflict. Occupational groups strive to achieve professional status, understood as the ability to claim exclusive jurisdiction over a specific set of tasks. 'Adjacent'

occupations, that is, occupations in closely related task domains (e.g., doctors and nurses), can come into conflict over attempts to invade one another's authority, or establish one-way dependence (Abbot, 1988). Authority over artefacts can reinforce or alter the boundaries between the tasks performed by specific groups; for instance, in the process of producing a new machine, designers use drawings and technicians use physical prototypes to assert and enforce their individual authority (Bechky, 2003a).

### Artefacts generic to occupations

Artefacts generic to occupations are used by the members of an organization independent of their specific occupation. Office furniture is an example of a generic, silent, occupational artefact. Among speaking artefacts, organizational procedures, discussed above, are typically generic to occupations – although the definition of the procedures for carrying out a task (e.g., a medical protocol) may be occupation specific. An important mechanism through which silent artefacts generic to occupations contribute to patterned action, is their value as symbols, an aspect that is explored extensively in cultural studies of organizations (e.g. Gagliardi, 1992; Rafaeli and Vilnai-Yavetz, 2004; Heracleus and Jacobs, 2008). Artefacts embody and display a particular set of values, suggesting courses of action that are coherent with the values of the organization. For instance, an 'open door' office policy encourages work colleagues to drop in on one another. Thus, artefacts with a strong symbolic dimension have a normative value and can be seen as part of the ostensive aspect of an organizational routine (Pentland and Feldman, 2008). However, symbolic messages need to be interpreted in order to affect behaviour, so that symbolic function of generic silent artefacts provides less stringent patterning than affordances of action.

### Artefacts as systems

Research on routines is beginning to highlight the need to focus on the relationship among a range of different artefacts. D'Adderio (2008) refers to the need to look at how procedures enrol human and material actors, in order to study their stability. In a study of roadmapping routines, Howard-Grenville (2005) argues that routines that make use of reinforcing rather than competing sets of artefacts may be

more persistent. Research in several fields provide suggestions on how artefacts may work as systems and reinforce one another.

Research into distributed cognition shows that coordinated action (including distributed problem-solving) relies on interdependent artefacts. For instance, a ship's position is determined through a set of coordinated activities mediated by the 'propagation of representational states across a series of representational media' (e.g., photometer, sighting telescopes, navigation charts) (Hutchins, 1995). Similarly, the revolutions in the organization of production, introduced by Taylor and Ford, would have been impossible without systems of supporting artefacts, including standardized parts. Studies of organizational memory show that individuals and groups rely on a variety of objects to support their recall efforts, and that organizational memory is stored in many distributed, complementing and partly overlapping artefacts which individuals combine to suit their needs (Ackerman and Halverson, 2004; Cacciatori, 2008).

While these contributions document the interdependencies among the artefacts supporting human activities, they treat all artefacts as equally important. Building on a variety of theoretical approaches to the role of materiality in cross-disciplinary collaboration, Nicolini, Mengis and Swan (2011) propose a hierarchical view of artefacts. Collaboration across disciplinary boundaries is enabled by a set of taken-for-granted artefacts that remain in the background, but provide the infrastructure for other artefacts working as boundary objects to facilitate collaboration. Motivation and emotional binding among participants is instead provided by the artefacts whose development is the objective of collaboration. Social studies of science provide important insights into how artefacts can be arranged in ways that are mutually reinforcing, using the notion of 'standardized packages' (Fujimura, 1992). Fujimura is interested in ideas, rather than stable patterns of behaviour and in 'facts' becoming 'stabilized', or accepted as such in science. Fujimura (1992) argues that, because of their high reconfigurability in local settings, boundary objects enable collaboration, but make fact stabilization more difficult. Boundary objects are so plastic that they allow the creation and maintenance of divergent interpretations and could serve competing scientific theories in their efforts to stabilize their own facts. Fujimura argues that to enable a particular

theory to dominate, collaboration across scientific communities requires a 'standardized package', i.e. a '*gray box* which combines several boundary objects […] with standardised methods […] in ways which further restrict and define each. Such codefinition and corestriction narrows the range of possible actions and practices but does not entirely defines them' (Fujimura, 1992, p. 169-170, emphasis in original). In Fujimura's approach, the key boundary objects in a standardized package are immaterial objects, that is, concepts. The significance of a standardized package is its ability to provide concepts that are sufficiently general and plastic (and, therefore, somewhat imprecise) to be adaptable to local concerns, alongside standardized methodologies that change local practice to the extent that its results reinforce the theory.

The categories developed here facilitate the analysis of the role of artefacts in the development of new routines. In order to lay the ground for the empirical exploration of how different artefacts perform in systems in relation to routinization, the next section introduce the settings of the case study.

## RESEARCH SETTING

This paper is based on qualitative, situated research conducted as part of a three-year, in-depth case study of a large British engineering consulting and support services provider firm operating in the British building industry. The British building industry has undergone important organizational changes (Cacciatori and Jacobides 2005), two of which are particularly relevant for this study. The first is the diffusion of *integrated procurement routes*, including a public procurement scheme known as the Private Finance Initiative (PFI), in which a single firm wins a contract covering the phases of a facility's life cycle, from financing to maintenance, for a period of 25 to 30 years. By bundling together previously, rigidly separated procurement phases, PFI provides strong incentives for firms to integrate the knowledge bases of the construction industry occupations in order to reduce costs and provide a better service. Therefore, this industry provides an excellent setting for an examination of the development of the new organizational routines through which this integration is achieved.

The second noteworthy feature of this industry is the intense *occupational competition* among the traditional professions (architects, engineers, quantity surveyors), general contractors and facilities managers. Among western countries, the cost consulting profession of quantity surveying is unique to the UK. The quantity surveyor's remit in traditional, specialized procurement is to monitor the building contractor by estimating the cost of construction through the 'Bill of Quantities' (a list of materials to be used). The services offered by the actors in the building industry increasingly are overlapping (Cacciatori and Jacobides 2005), and reports from professional bodies and in the trade press indicate a full-blown 'jurisdictional war' (Abbott, 1988).

Against this background, the case study company, Design Engineering & Facilities Management (DE&FM), opted to reposition itself as an 'integrated services provider'[ii] (see Davies, 2003). This involved a continuous acquisition campaign in the late 1980s and through most of the 1990s, so that by the end of the 1990s DE&FM was operating in project financing, in all engineering fields and in architecture, in cost consulting, and in the growing facilities management market. The case study focuses on DE&FM's efforts to develop a new bidding routine for integrated PFI school projects.

# METHODS

## Within-company sampling and data gathering

During the preliminary, exploratory fieldwork, I collected information on the company, its history and its politics, and identified the bidding process as the focus of the company's innovation efforts. I then concentrated on bidding and conducted 26 interviews with individuals involved in bidding for PFI and other projects. Interviewees included directors of the various business units, project managers, technical staff at different levels of seniority (engineers and architects), and support staff involved in managing the information to support bidding. I gathered as much documentation on the bidding process (procedures, checklists, samples of bids submitted) as possible, in order to familiarize myself with the issue and identify specific units for detailed analysis. During this phase, I identified bidding for PFI projects as the

area involving the most complex and most vigorously pursued efforts to develop new routines. I also noted the attention devoted to whole-life costing tools within the bidding process.

In the final phase of the fieldwork, I reconstructed the evolution of whole-life costing tools and the PFI bidding process, through direct observation and information from 14 more interviews including 7 with the three cost consultants responsible for the development of whole-life costing and 7 in other parts of the company, including DE&FM Invest, the Design Division and the Facilities Management Division. I attended three meetings between representatives of the company and the whole-life costing system developers and other actors, and searched internal company documentation (e.g. manuals, presentations, the company Intranet). The company 'tutor' (who acted as my main contact in the company) helped to identify the first three interviewees for my enquiry into whole-life costing; the rest were selected using a combination of theoretical sampling and snowballing, that is, I asked interviewees to refer me to (a) people in other parts of the company directly involved in the development of the tool (key informants) and (b) people likely to offer alternative, controversial views. The interviews provided competing accounts of the development, role and aims of the tools being developed, which ensured multivocality. One interview, with the main developer of the whole-life costing tool, was conducted one year after the end of the main fieldwork in order to get an update on the state of the company.

In addition to gathering information on the interviewee's background, current position and role in bidding, the interviews were aimed at finding out what the interviewees considered to be important, and their perspectives on these issues. I followed Dougherty (1992, p.184) and conducted interviews that were 'structured around […] general questions, but unstructured regarding what the person chose to emphasize'. The general questions varied over the phases of the fieldwork and depending on the interviewees' specific expertise or roles. Parts of the four interviews with the main developer of the whole-life costing tools followed a different pattern and were directed to understanding the tools and their intended role in the process. I discontinued the interviewing when I reached what Glaser and Strauss (1967) call *theoretical saturation*, that is, when the information being provided was helpful for understanding the process, but was adding no new theoretical categories or critical issues.

Since the interview topics were often a source of organizational conflict, I decided not to tape the interviews to ensure that interviewees would be more open (Rubin and Rubin, 2005). My interview notes were ordered and written up as soon as possible after the interview and combined with the other material collected. When factual information was an important part of the interview (e.g., when reconstructing the corporate initiative on PFI bidding), I sent summaries to the interviewees for verification.

The confidentiality agreement I had signed with the company allowed access to internal documentation related to the whole-life costing tools (e.g. manuals, presentations, company material available on the company's Intranet), a printed copy of the first version of the tool for a specific project (whose interpretation I checked with interviewees), on-site access to the modified (actual and intended) Life Cycle Replacement (LCR) Model and the Service Life Planner (SLP), and on-site access to a set of whole-life costing tools developed by the cost consulting division, not discussed in this paper. I wrote reports outlining the functionalities and data sources of the tools (actual and intended), which featured tables of their intended used within the bidding process. The accuracy of these reports was checked by the cost consultant in charge of the project. I was also given full access to the new procedures.

## Data analysis

I used a 'temporal bracketing' strategy to analyse the material collected during the fieldwork in order to develop a process model of routine evolution. Temporal bracketing enables the handling of heterogeneous data, and is coherent with the structuration lens of the study (Langley, 1999). By adopting this strategy, I was able to analyse the eclectic material at my disposal (company archival material, interviews, the whole life costing tools themselves, meeting notes, and grey literature on the evolution of the British construction industry) and to identify three periods in the evolution of the PFI bidding process. During the first period, the company used variations of its existing bidding routines. This period makes it possible to identify the resources that structures make available to agents. During the second period, agents used the resources at their disposal to introduce a new bidding process. In this period is therefore possible to examine how agency takes place. During the third period, the company attempted to implement the new

process, with very limited success – making it possible to compare and contrast areas of success and failure.

I conducted iterative data analysis, involving re-reading and cross-examination of my interview notes, and comparison between the accounts given by interviewees and the story that emerged from the whole-life costing tools themselves and their development. This enabled the identification of common patterns and points of contrast. Actors' accounts of unfolding events are important because they provide contrasting interpretations and stated motivations, which contribute to constructing the practice. I used a very simple form of thematic coding to highlight the differences in actors' perspectives and identify typical statements, recurring issues and common terms (Flick, 2002). The interviews on the whole-life costing tools provided statements that were revealing about the interviewees' understanding of what the process entailed and its relevant costs. I analysed the data as they were gathered, and returned to them repeatedly as the fieldwork progressed, to compare my analysis new insights.

I cross-checked accounts using three different means (Miles and Huberman, 1994). First, I contrasted and compared interviews, highlighting discrepancies which were investigated through follow up questions or, where relevant, addressed in successive interviews. Second, I conducted a detailed examination of the artefacts supporting the practice of bidding. As much research in this area shows (e.g., Bechky, 2003; Bowker and Star, 1999), the 'voices' of the objects and the stories told by their structure and characteristics are important counterpoints to interviewees' stated motivations and aims. Third, I gathered extensive documentation from academic work and trade press on the evolution of the British construction sector. This enabled me to map correspondences and divergences in the strategic choices of professions and professional firms in the industry, against my findings in DE&FM. I stopped the process of triangulation when discrepancies were resolved or if I found evidence of persistent difference in the accounts. This enabled me to develop an articulated understanding or 'theory' through which I could read and reconcile the empirical phenomena I was observing, and allowed me to identify gaps and shortcomings in the conceptual schemes developed so far to account for the dynamics of the development of routines (Eisenhardt, 1989).

## THE CASE: BIDDING FOR PFI PROJECTS IN DE&FM

Producing a bid for a PFI school project required collaboration among four organizational units: DE&FM Invest, which reported directly to the CEO and represented DE&FM as the investor; the Design Division (housing architects and engineers); the Facilities Management (FM) Division; and the Cost Consulting Division (housing the firm's quantity surveyors). With the exception of the Design Division, which operated as subcontractor to the construction contractor, these organizational units were linked through individual contracts to the 'project company', the legal entity created to undertake each PFI project. Efforts to develop a new bidding routine for PFI school projects took place in three phases. The first was a period of emergent change and local adaptation of traditional design routines. In the second phase, incremental changes were perceived as inadequate; a corporate initiative was launched to develop a new bidding process and new tools and procedures were developed to support the new bidding process. In the third phase the new tools and procedures were implemented.

### Phase one: adapting routines and stretching artefacts

DE&FM organizations members tried to adapt existing bidding routines to the different demands of PFI projects. This entailed the 'stretching' of artefacts used in existing routines to support novel patterns of interaction. This is apparent in the case of product representations, sketches and drawings. In preparing a PFI bid, contractors, subcontractors and facilities managers are required to give feedback on design choices at an early stage in the bidding process, the so called 'conceptual' stage, on the basis of sketches or, at most, conceptual drawings. However, they required detailed drawings, normally produced much later, in order to give this feedback:

> We keep having a lot of trouble with contractors. You see, they are used to preparing their bid on the basis of detailed design and want us to complete the design so that they can calculate construction costs. However, they only pay our variable costs for bidding activities. [Assistant Bid Manager - DE&FM Invest ].

As a result, designers were receiving feedback at the end of the bid preparation process, when time pressures were great and when changes to design were difficult and costly, and could introduce problems in other areas. For instance, the choice of a different type of fire system could involve different health and safety requirements.

The difficulty of giving and receiving feedback based on drawings was combined with uncertainty (and attendant experimentation) about how to divide tasks among the different groups. The Director of DE&FM Invest–School Unit emphasized that setting up a bidding process meant identifying and addressing the numerous and unfamiliar interdependencies among project components. In interview, he gave examples of how new ways of dividing labour were needed for PFI projects to avoid the bidding process grinding to a halt. New arrangements were worked out during the course of every project, contributing to the feeling that the process was unstable and that bid meetings, during which key decisions on the content of the bid should have been made, were ineffective. An assistant bid manager said that:

> There are just too many people in the room and you cannot get anything done. We had one of these meetings just recently on the … bid. Between designers, facilities managers, cost consultants, the contractor and a few subcontractors we were about 20 – everybody was happy that they could come, but we managed to decide very little and it cost a lot of money [DE&FM Assistant PFI Bid Manager].

Since sketches and drawings were perceived as insufficient to structure the process in the new context, new artefacts were developed – including representations of processes generic to occupations (i.e., checklists) and occupation-specific product representations (e.g., FM Division design requirement manuals).

One of the new speaking artefacts was an Excel Workbook developed to estimate the total cost of a building over its lifetime. There is often a trade off between capital (i.e., construction) costs and maintenance costs. For instance, a cheaper roof may require more frequent maintenance. Design decisions related to reducing total costs must be informed by these trade-offs. The Excel Workbook, or LCR Model, was a new cost estimating tool developed to address these trade-offs. It was physically located on the

laptop of the quantity surveyor assigned to PFI projects. The structure of the LCR Model and its links to both occupational groups and tasks are shown in Figure 2. The solid lines identify the sections of the tool for which each organizational unit was responsible. The first section, developed by the Cost Consulting Division, estimated *Capital Cost* and included periodic replacement of capital items such as elevators, heating system, etc. (i.e., life cycle replacement costs*)*. The second section, developed by the FM Division, estimated other *Occupancy Costs* – that is, the costs of using the building, in particular repairs, and costs such as cleaning, catering, etc. The third section, the responsibility of DE&FM Invest and not discussed here, estimated *Tax and Financial Costs*, and the fourth section calculated the total costs of the building over its lifetime. The dotted line separates the parts of the tools used by the different organizational units (shown in ovals) to carry out their tasks.

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FIGURE 2 ABOUT HERE

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The Excel Workbook was a new boundary object, developed to complement the inter-occupational problem-solving taking place around drawings with cost information. Like many boundary objects, it was a patchwork representing the needs and contributions of different occupational groups (cf. Bowker and Star, 1999). Figure 2 shows that its structure reflected the boundaries between occupations and organizational units (cf. Cacciatori, 2008). It also showed a mismatch. Life cycle replacement costs are costs sustained during occupancy, not construction. They become the responsibility of the FM Division once the school is built. However, the quantity surveyors included them in their section on the basis that they were 'just deferred capital costs'. The mismatched structure of the LCR Model in relation to the life cycle replacement costs highlights the conflict between quantity surveyors and facilities managers over the estimation of maintenance costs. This conflict will come to fruition in Phase 3.

## Phase 2: engineering systems of artefacts

The way that the LCR Model represented knowledge complicated its use as boundary object. The LCR Model was too flexible: it supported local, occupation-specific representation, but did not allow reintegration into a global representation because of the different ways in which costs were expressed. Capital and replacement costs were expressed through quantity surveyors' traditional building elements (e.g., roof, foundations, etc.), and maintenance costs were expressed as types (e.g., utilities, security, repairs and maintenance) and in cost per square metre. This did not allow easy comparison among different design choices in terms of total costs. There were also problems with how each occupation-specific representation worked in terms of ease of manipulation. The LCR Model provided alternative specifications for building elements in piecemeal fashion. Also, changes to design specifications had to be copied manually into worksheets, making it difficult to compare configurations and identify the changes that had the greatest impact on costs (see Comments box in Figure 2).

Following serious delays in the preparation of two consecutive draft bids for PFI school projects, the Cost Consulting Division and the corporate R&D Unit were given funding to work on improvements to whole-life cost estimation and to develop new bidding procedures.

### *The modified LCR Model*

Mark, a then recently hired cost consultant in the Cost Consulting Division, was assigned to improving the whole-life costing tools. The changes he introduced are depicted in Figure 3 (intended). He increased the global representation capabilities of the LCR by developing a new, occupation specific product representation, the SLP. The SLP was an Access database, in which the building elements used in the cost consultants' classifications were extended, with some adaptation, to include facilities management costs. In Mark's plan, data on maintenance costs would be provided by the FM Division, which potentially could estimate very accurate maintenance costs using the software that was used to dispatch repair contractors and handled billing. The SLP included several options for each building element, and changes made in one section were automatically applied to the other sections (see Comments box in Figure 3). The

SLP linked capital and life cycle replacement costs to other maintenance costs. However, because it required facilities managers to stop expressing their costs as costs per square metre, adaptability to local use decreased.

The LCR Model and the SLP were linked. The LCR Model incorporated a copy of the SLP, so that it was possible to select building elements from a drop-down menu. This was done so that the SLP could be maintained and updated centrally, while the LCR Model was used in projects. The left-hand side of Figure 3 shows the intended new configuration of the tool.

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FIGURE 3 ABOUT HERE

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Routinized behaviour relies on connections among individuals (Feldman and Rafaeli, 2000; Turner and Rindova, 2011), which, in turn, reflect the communications paths required to deal with the interdependencies among different parts of the product (Henderson and Clark 1990). Mark's work on the LCR Model and the SLP shows how agents purposefully craft product representations and their connections in order to shape the communication patterns that make up routines. Mark configured the structure of the LCR Model, its relationships with the new SLP and, potentially, with the FM Division's operational software, according to his view of the appropriate way to represent costs and the appropriate flow of information, which differed from that of facilities managers'. In describing their method of costing buildings, cost consultants made comparisons with the approach of facilities managers:

> Quantity surveyors bring to the process the ability to prioritize …. FM people have a contractor not a consulting frame of mind. They provide, not optimize. [Cost Consulting Division, Director]

Cost consultants have what could be termed a "function oriented" way of thinking about costs, in which costs depend on technical specifications of building elements, decided on the basis of the functions required of a particular area of the building (e.g., front vs. back office). The structure of the LCR Model and SLP reflected this understanding of costs, as opposed to the more operational understanding of facilities managers – that focused on ease of maintenance.

*Development of procedures*

The development of new, occupation-specific product representations was complemented by the development of new generic process representations in the form of bidding procedures. The new bidding procedures were developed with input from Mark related to the newly introduced 'value engineering meetings'. The focus of these meetings was analysis of the interdependencies between design, construction and facilities management costs. They were chaired by a cost consultant (bid meeting were chaired by the bid manager, and design meetings were chaired by a designer), and were held before the other meetings. The new procedures introduced two new organizational roles dedicated to the estimation of whole-life costs: an advisor to the construction, design and facilities management teams who also coordinated the value engineering meetings; an advisor to the project company, a role similar to the traditional role of quantity surveyor.

The development of procedures illustrates the complementarities among product and process representations in the strategies used by actors to pattern organizational behaviour. Identification of the important product features and their interdependencies through the LCR Model and SLP is implicitly normative since it suggests a particular division of labour and gives voice to certain concerns (e.g., costs) and not others (e.g., value creation in terms of quality of teaching environment). As suggested by Pentland and Feldman (2008), the LCR Model and the SLP, on their own can have only a limited influence in the sense that they can only 'enable and constrain' the actions that take place through them. Indeed, they only succeeded in locally patterning actions in the bidding process in Phase 3. The division of labour implicit in each product representation needs to be reinforced and extended, which is achieved by bundling them with organizational procedures. These procedures match activities to roles, further clarify the patterns of interdependence and communication among roles, and provide a temporal sequencing of activities. Thus, product representations that work as boundary objects and process representations, act in mutually reinforcing way similar to the complementarity between concepts and methods in science (cf. Fujimura, 1992). This combination helps in addressing the trade-off in product

representations between the flexibility needed for problem-solving and the rigidity necessary to funnel action. Flexible product representations when combined with procedures can, as a system, exhibit sufficient rigidity to funnel action and sufficient flexibility to enable problem-solving.

### Phase 3: occupation specific artefacts and organizational conflict

While Phases 1 and 2 relate primarily to the role of speaking artefacts and how they represent knowledge, Phase 3 highlights the important occupation-specific nature of the artefacts. The new group of artefacts, consisting of the LCR, the SLP, and the procedures, was not adopted in the way Mark had envisaged. Mark incorporated into the LCR Model only the SLP sections related to capital and life cycle replacement costs (see Figure 3 – Actual). Because of the significant resistance from the FM Division to the new procedures and its refusal to provide data on maintenance costs, Mark continued to use the facilities management classification for other facilities management costs.

The interviews show that senior FM Division staff were sceptical about the new procedures and questioned the cost consultants' contribution. An executive in the FM Division said:

> The QS Division consultants are very expensive. They want our data to sell them back to us, so we are starting to develop our cost model.

Because Mark did not have information on what cost data the FM Division held, and was aware of the tensions within the company, he decided to continue using the original FM Division components to prevent further friction. This partially modified version of the LCR Model reduced some of the problems, and addressed the need for a flexible representation by providing the possibility to choose building elements and to update the worksheets automatically. At the same time, it required (and obtained) minimum collaboration from the FM Division.

Mark began to use the new SLP to facilitate discussion of different design options in the value engineering meetings at the early 'conceptual design' stage. He commented that:

> Architects' rush to produce drawings is counterproductive really. A first discussion should focus on general approaches to optimize whole life costing through the use of the SLP and the facilitation of a cost consultant.

A few interviewees referred to the more positive interactions during value engineering meetings, and that they were a result of the SLP and modified LCR Model and Mark's facilitation. However, designers often did not show up at presentations on the new whole-life costing tools, and Mark was not always notified about the design and value engineering meetings which, according to the new procedures, he should be facilitating. An interview with Mark a year after the main fieldwork revealed that the situation had not changed. Therefore, while the SLP facilitated a degree of restructuring of the bidding process in relation to the conceptual design phase, and both the SLP and the 'actual' version of the modified LCR Model improved problem-solving, the more integrated tools were not adopted and the bidding procedures were largely ignored, so that a new overall bidding routine did not develop.

Why did Mark's efforts have only limited success in reshaping DE&FM PFI bidding routine? Looking at the occupation specific nature of the systems of artefacts that should have supported the new routine helps to answer this question. The LCR Model and the SLP evolved from the quantity surveyors' occupation specific tools. Although they incorporated representations of other occupations and were used as boundary objects, they were physically controlled by the quantity surveyors. Quantity surveyors had them on their laptops. They were used and manipulated during cross-occupation meetings by the quantity surveyors. By crafting the way they represented the product and worked as a system with procedures and drawings, the quantity surveyors attempted to stabilize patterns of actions that gave them control over a larger set of activities, at the expense of both facilities managers and designers. An artefact specific to an occupation (the LCR Model) was combined with a generic artefact (procedures, which introduced roles associated with the artefacts) to extend the reach of the sponsoring occupation within the overall PFI bidding process. This combination enabled the development of new tasks and new roles, which were bundled with the object and brought new activities within control of the originating group. Continued ownership of the tool by quantity surveyors was crucial because new roles as described in procedures are justified on the basis of mastery of the new tool, and because the activities carried out by other occupations are represented in the tool, which enables later claims for full responsibility of the activities.

In this way, quantity surveyors aimed at appropriating cost estimation tasks related to life cycle replacement and maintenance that were the contractual responsibility of facilities managers. At the conceptual design stage, the new tools were intended partially to displace drawings and, therefore, designers. This is evident in Mark's negative evaluation of architects' 'rush' to produce drawings, the introduction of value engineering meetings facilitated by a cost consultant at the conceptual design stage, and the development of two new roles connected with whole-life costing estimation.

Beyond extending quantity surveyors control over a lager span of the bidding process, the way in which the SLP and its relationship with the modified LCR Model were structured implies an important change in the control over the knowledge accumulation underpinning consulting on whole-life costing. By relying on heterogeneous classifications, the original LCR Model accessed data from the various communities. However, the databases and expertise that were the source of these data remained under the control of each occupation. The introduction of the SLP changed this. The design of the LCR Model *in combination* with the SLP effectively decoupled maintenance and the updating of occupancy information, from application of the tool in specific projects. This separation allowed the cost consultants to accumulate expertise in whole-life costing, a profitable service and a 'contested terrain' (Abbott, 1988) in the industry.

The FM Division in DE&FM did agree to use the partially modified version of the LCR model (Figure 3, actual), despite the quantity surveyors annexing estimation of capital replacement costs already in Phase 2. Thus, the partially modified LCR Model and the interaction patterns it sustained responded to the problem-solving needs of PFI bidding while at the same time constituting a truce in the ongoing organizational and occupational struggle. The sub-optimal problem-solving it afforded derived from the need to sustain interaction patterns in which a truce among occupations could be preserved. Conversely, the modifications Mark made to the LCR model were a considerable improvement from a problem-solving point of view, but were unacceptable in terms of a truce in the jurisdictional war between quantity surveyors, facilities managers and (to an extent) designers.

## AGENCY THROUGH SYSTEMS OF ARTEFACTS IN THE DEVELOPMENT OF NEW ROUTINES

Including artefacts in the analysis, rather than focusing exclusively on individual's actions and cognitions, allows to develop a better appreciation of the role of individual agency in the development of new routines. DE&FM data show how the effort of developing a new routine was strongly dependent on the action of individuals, particularly Mark. In line with approaches that underline the dual nature of structures, the data show that these actions were not totally independent nor were they totally determined by the structures in which Mark was embedded. Mark's action was constrained by the resources that provided by structures, especially the artefacts, frames and objectives of his profession (cf. Kaghan and Lounsbury, 2006). His actions were further constrained by the fact that other actors in the system had access to similar resources. However, Mark exercised agency by inventively modifying resources and moving them across different, but intersecting, structures in an effort to modify them, that is, to create a new routine (cf. Sewell, 1992).

Material resource, in the form of systems of interacting artefacts, are therefore important mediators in the institutionalization of individual agency into new routines. Speaking artefacts mediate efforts to develop patterns of actions that address problem solving needs. Specifically, product representations mediate the process through which individual agents attempt to match novel technical interdependencies in the product with a novel pattern of interdependent, distributed actions in the organization. Examination of the occupation-specific nature of these artefacts allows a reintegration of the analysis of conflict into problem-solving, showing that by altering the way in which product representations embody knowledge, agents attempt to both address problem-solving needs and alter control over activities and over knowledge accumulation. The attendant patterns of action are reinforced and extended by bundling the representations of products with representations of process. The limited span of influence of individual artefacts in a process (Pentland and Feldman 2008) is less of a limitation in their role in patterning behaviour when one looks at systems of reinforcing artefacts. The implication of these systems in terms

of organizational conflict and, in particular, the kind of truce these systems embody becomes instead relevant in determining whether or not a new routine emerges.

The evidence in this case suggest a model in which new routines are developed when organizations face environmental demands, such as the introduction of PFI, that force them to change their products (Nelson and Winter, 1982). This entails changes in the required bodies of knowledge, or at least a readjustment of the communication patterns among specialists deriving from changes in product architecture (Henderson and Clark, 1990). In their first attempts to deal with these demands, people use their experience of similar processes and adapt them incrementally to the new circumstances (cf. Turner and Fern, this issue). This entails the 'stretching' of the systems of artefacts that supported the previous routines to the new demands. One or more (competing) patterns of interdependencies in the product (and alternative divisions of labour) emerge. If the current systems of artefacts, and specifically the occupation-specific product representations of the group currently dominating the process, is deemed insufficient to respond to the new demands, other groups will try to make inroads into the process using their own occupation-specific product representations. For instance, in DE&FM, when drawings began to be seen as inadequate to structure the process, the cost consultants stepped in with their LCR Model, a modified bill of quantities. Since new product features and new product architectures require the management of new interdependencies, the occupation-specific objects most likely to be modified are those used for decision making involving several different groups. Intentional modifications to occupation-specific objects enable groups to exploit the opportunity offered by a new critical environmental uncertainty, to increase their centrality in the organizational process (cf. Hinings, Hickson, Pennings et al., 1974). The modified tool becomes a boundary object because it is used to address interdependencies among the bodies of knowledge held by different groups. This modified occupation-specific artefact, sustaining a modified pattern of problem-solving and a new truce, may simply come to operate in parallel with existing ones in a partially modified routine.

Alternatively, the routine, and the occupation-specific objects supporting the new routine, may enter a new and critical phase of development if there is agreement that incremental changes are inadequate. At

this stage, packages of mutually reinforcing artefacts are developed, typically including one or more occupation- specific product representations, which act as boundary objects, and generic process representations. The bundling of product and process representations supports problem solving while extending the control of the occupation owning the artefacts over part of the process.

The occupation owning the artefacts may also try to increase its control of knowledge accumulation. To do so, the originating occupation needs first to extend its capacity for knowledge representation to enable manipulation of other groups' knowledge. Second, the new tool must be linked to other objects in other groups in a way that feeds experience into the new artefact. Third, local, specific problem-solving must be decoupled from the processes involved in updating and revising knowledge. The success of these strategies depends on the ability of the sponsoring occupation to craft the system of artefacts in a way that addresses problem-solving demands in a way that is deemed acceptable, while at the same time supporting a division of labour that constitutes an acceptable truce. Figure 5 highlights the main features of this process, showing the interacting nature of the artefacts that sustain a routines, and how environmental changes can lead artefacts, and the occupation to which they belong, from the periphery to the core of an organizational process. This mechanism, which is similar to the one discussed by March (1991), highlights the benefits of internal diversity and latent conflict in providing organizations with the resources to deal with environmental change.

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INSERT FIGURE 5 ABOUT HERE

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## CONCLUSIONS

The approach developed in this paper makes it possible to address a central and unresolved issue in the development of new routines, that is, their dual functioning as organizational memory and as truces. These aspects of routines have been examined in isolation, with more effort devoted to examining the memory and cognitive dimensions than to examining their truce dimension (Becker, 2004, 2005). In

considering routines as memory, the patterning of action is expected to reflect the 'characteristics of the information storage problem that they solve' and in considering routines as truces, the patterning of action is expected to 'reflect the features of the underlying problem of diverging […] interests' (Nelson and Winter, 1982, pp. 110-111). Understanding how routines develop, therefore, requires an understanding of how the patterning that enables routines to fulfil the function of memory overlaps with the patterning that enables them to act as truces. This paper shows that this overlapping occurs because development of routines is mediated by the development of systems of artefacts, which, within their own structures and relationships, reproduce the structures of problem-solving and of intraorganizational conflict.

The analysis in this paper points to some of the open questions related to the multilevel nature and different characterisations of routines that need to be addressed. The first is the relationship between routines and individual skills and competencies. Work that treats routines as collective entities relies on analogies between routines as organizational level constructs, and individual skills, but provides very little analysis of their links (Felin and Foss, 2009; Salvato and Rerup, 2011). In occupation specific speaking artefacts, some of these links start to become clearer. These artefacts embody occupational knowledge and assumptions, and the expertise of those developing them. They regulate the type and timing of the expertise exploited for problem-solving. Thus, artefacts are important links between individual skills and routines, and their role as mediators in this relationship, and in the process that transforms firm experience into capabilities, needs further study. A second and related issue is the relationship between conceptualizations of routines as dispositions and cognitive regularities on the one hand, and routines as patterns of action on the other (Becker, 2004; Cohen, 2007; Salvato and Rerup, 2011). Because they contain formal representations of knowledge, speaking artefacts, which funnel and bound action, have a direct relationship with cognition. Similarly, occupation specific artefacts embody and promote tendencies to act in certain ways in relation to organizational conflict. Reconciling these opposing conceptualizations of routines would be a promising avenue for research.

This study contributes also to the growing body of research on the material mediation of inter-disciplinary problem-solving. By analysing the process of development rather than the characteristics of

existing boundary objects this study shows that occupational groups can gain influence by generating boundary objects that sit at the junction of, and regulate access to, areas of expertise, which then can be annexed. Examining the occupation-specific nature of boundary objects contributes to analyses aimed at reintegrating conflict into the analysis of problem solving (Orlikowski 1992; Kaplan, 2011; Nicolini, Menges and Swan, 2011), moving beyond the focus in the literature on either problem-solving (e.g., Carlile, 2002; Bechky, 2003b) or conflict (e.g., Barley, 1986; Bechky, 2003a).

This study has some limitations which also offer opportunities for further research. The organizational routine examined here has a strong problem-solving component and requires collaboration among occupations that are either professions or are seeking professional status. Further research could investigate the processes through which artefacts mediate the development of new routines in contexts where joint cross-occupation problem-solving is less important. Also, the role of silent artefacts (e.g., clay models and other physical prototypes) in the processes of routinization, and their relationships with speaking artefacts offers further opportunity to clarify how new routines are developed.

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**Figure 1 – A typology of artefacts**

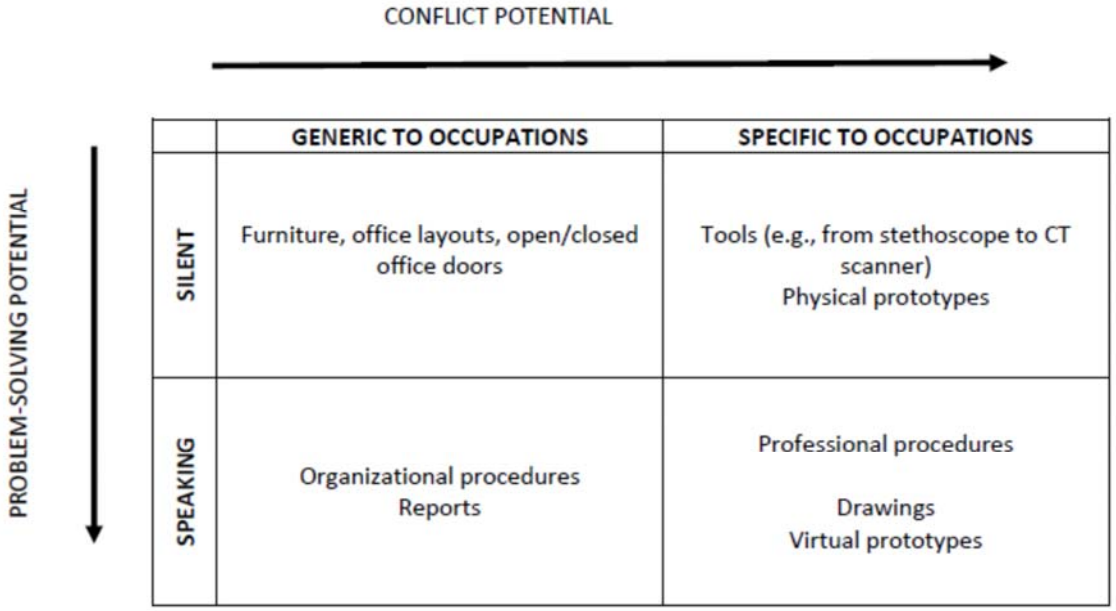


**Figure 2 – The LCR Model before the PFI Initiative**

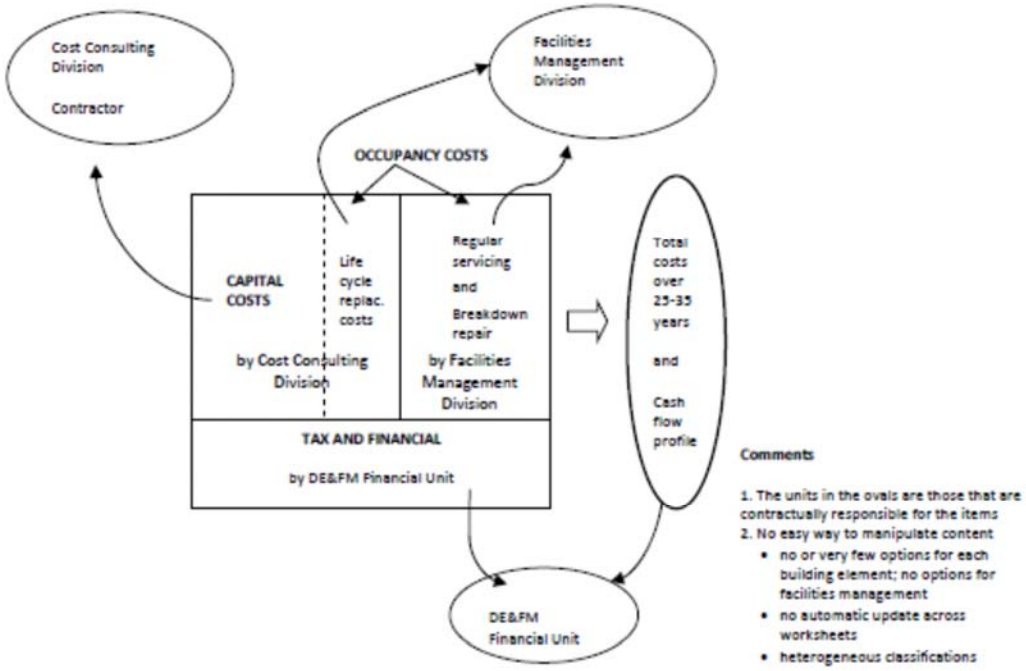


**Figure 3 – Whole-life costing tools after the PFI Initiative - Intended and actual configuration**

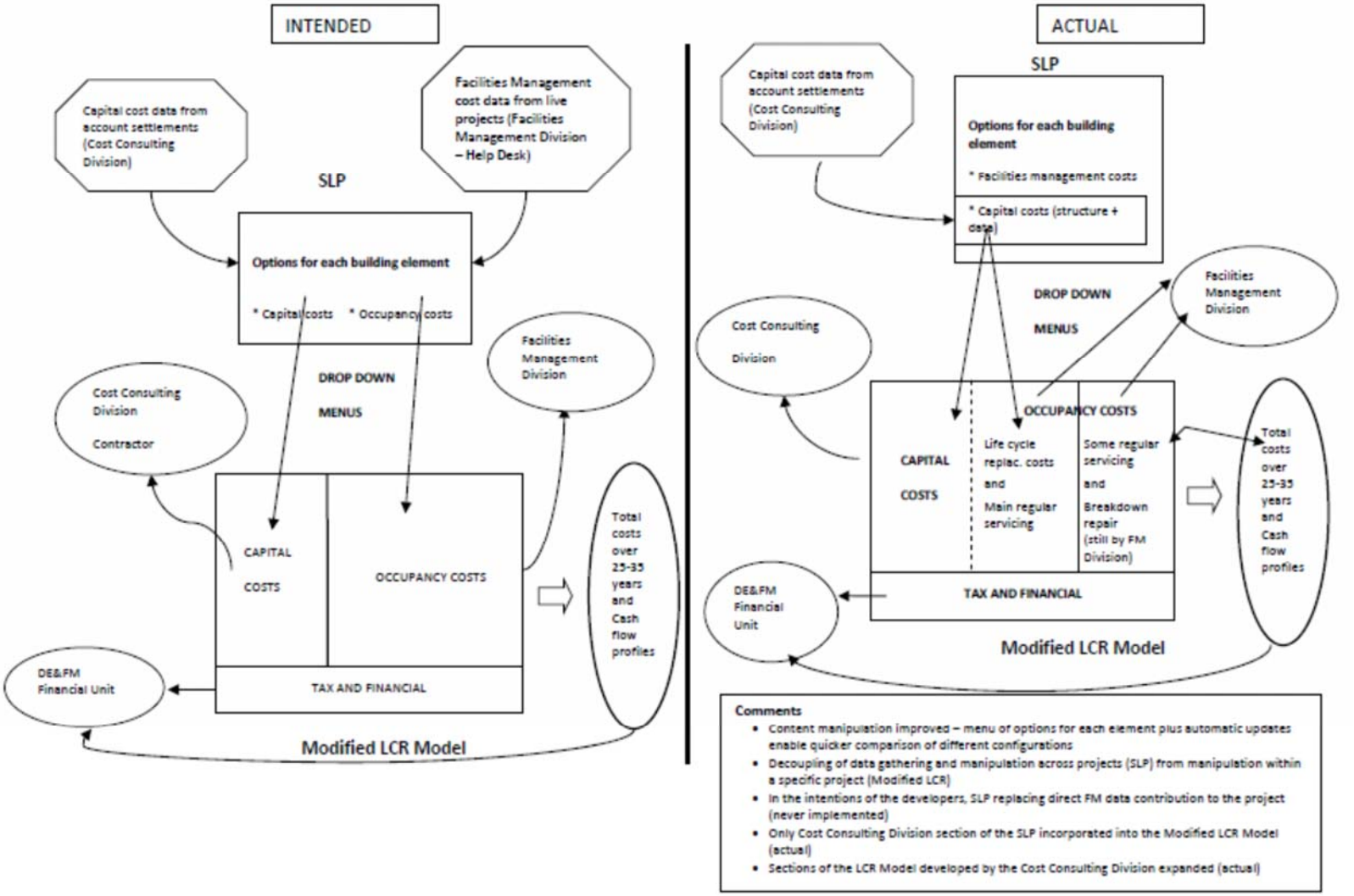
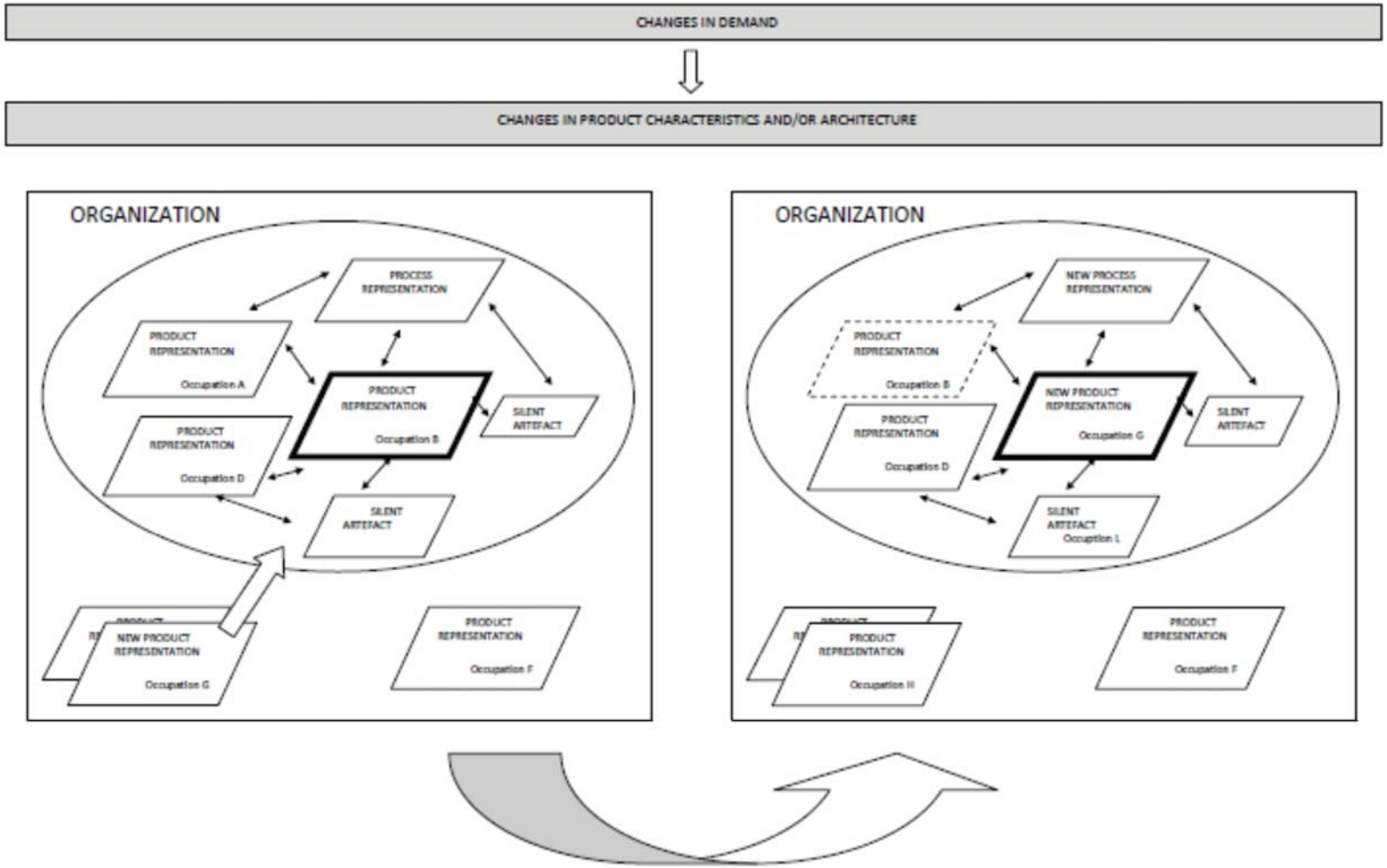


**Figure 4 – Systems of artefacts in the development of new routines**



**Appendix 1 - List of Acronyms**

| | |
|---|---|
| **DE&FM** | Design Engineering and Facilities Management (the case study company) |
| **FM(s)** | Facilities Manager(s)/Management |
| **LCR Model** | Life Cycle Replacement Model (the first whole-life costing tool developed in DE&FM) |
| **PFI** | Private Finance Initiative (public procurement method for construction) |
| **QS(s)** | Quantity Surveyor(s)/Surveying |
| **SLP** | Service Life Planner (Access database – core of the new whole-life costing tools storing all cost data) |

[i] A wide variety of objects, material and immaterial, have been described as boundary objects. Among artefacts, most studies have focused on speaking artefacts, such as Gant charts, which provide a locus for negotiating time allocations across groups in consultancies (Yakura, 2002)and many of the tools employed in project management (Sapsed and Salter 2004). Research on product representations as boundary objects has focused particularly on sketches and drawings ( Henderson, 1991) and virtual prototypes (e.g., Carlile 2002, 2004).

[ii] The name of the company, of all people mentioned in the following and of the objects and tools discussed were disguised to maintain anonymity. A list of acronyms is available in Appendix 1.