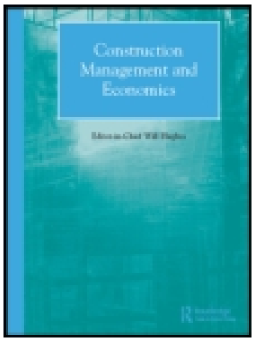

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Dynamics of inter-organizational knowledge creation and information technology use across object worlds: the case of an innovative construction project

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Organizational research argues that under relational forms of governance a high degree of both *information pooling* and *physical interaction* are necessary for inter-organizational knowledge creation. Yet, recent studies of information and communication technologies (ICTs) suggest that both practices at the same time are sometimes unnecessary. We address this discrepancy by developing a framework whereby the intensity and proportion of these inter-organizational practices are affected by the object world congruence between designers within and across partnering firms, and the level to which a common information technology platform is embedded in their activity. Through a multi-level case study of a Frank Gehry construction project we illustrate how designers with highly congruent object worlds, due to a strongly embedded common information technology platform, could jointly create knowledge despite decreased physical interaction. Conversely, designers from firms with incongruent object worlds or with congruent object worlds lacking a strongly embedded common ICT platform demanded a higher degree of physical interaction for effective knowledge creation. Our research suggests a dynamic, evolutionary model of inter-organizational knowledge creation influenced by variation in object world congruence and the levels of embedding a common ICT platform.

Keywords: Inter-organizational systems, information pooling, information technology, knowledge creation, project governance.

Introduction

Knowledge creation, such as that associated with innovative design activity, has historically been confined to the domain of hierarchies (Coase, 1937; Williamson, 1985). In recent years, however, such activity has become increasingly common *between* firms (Argyres, 1999; Helper *et al.*, 2000). The construction industry is no exception (Boland *et al.*, 2007; Taylor and Levitt, 2007). As a result, organizational theorists have recognized the significance of new *relational* forms of governance, which combine aspects of markets and hierarchies (Dyer and Singh, 1998), and are organized around projects (Gann and Salter, 2000). Although sparse, there are two broad streams of research on inter-organizational knowledge creation: the first emphasizes innovation and learning in projects (Brady and Davies, 2004; Bresnen *et al.*, 2004), and the second examines practices that bring about successful inter-organizational knowledge creation under relational forms (Powell *et al.*, 1996; Helper *et al.*, 2000). Both streams have largely neglected the impact of information and communication technologies (ICTs), though such technologies are often key mechanisms for inter-organizational knowledge coordination and creation (Malone *et al.*, 1987; Bresnen and Marshall, 2000).

Past research into inter-organizational knowledge creation has mainly investigated virtual team performance during product design, or impacts of virtualized design processes in complex industrial domains such as aerospace (Argyres, 1999; Majchrzak *et al.*, 2000).

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More recently, there have been some studies about ICT-enabled knowledge creation in the architecture, engineering and construction (AEC) industry (i.e. Yoo *et al.*, 2006; Boland *et al.*, 2007; Gal *et al.*, 2008). To date this research has reached somewhat inconsistent conclusions about the role of ICTs in enabling or inhibiting inter-organizational knowledge creation leaving several questions unanswered. On the one hand, some studies emphasize the necessity of face-to-face interaction for successful knowledge creation (e.g. Helper *et al.*, 2000; Helper and Khambete, 2005). On the other hand, some argue that much of the 'knowledge' can be embedded into interaction protocols and richer descriptive product design knowledge integrated into ICT based tools (e.g. Malone *et al.*, 1987; Argyres, 1999).

In this article we take steps towards addressing this discrepancy by developing a framework where the intensity and proportion of distinct information sharing practices during inter-organizational knowledge creation are seen to be affected by the object world congruence between designers. These *object worlds* (Bucciarelli, 1994) characterize the manner in which ICTs become embedded in design practices and comprise of a set of designer's tools, practices and physical environments as they go about designing. The worlds highlight differences between the impact of specific ICTs, which are embedded into design activity, and those which are not. Accordingly, object world congruence is affected by the level at which a common ICT platform has become embedded in the inter-firm design activity. Furthermore, we draw upon studies of inter-organizational governance to extract two distinct information sharing practices—*information pooling* and *physical interaction*—underpinning inter-organizational knowledge creation (Powell, 1990; Uzzi, 1997; Dyer and Singh, 1998; Inkpen and Dinur, 1998; Van de Ven *et al.*, 1999; Helper *et al.*, 2000).

By using these concepts we articulate a framework *in situ* of how ICT-enabled inter-organizational knowledge creation takes place during the design and construction of a highly complex building. We studied the design and construction of Frank Gehry's Peter B. Lewis Building in Cleveland, Ohio, USA, as a multi-level revelatory case study, and our objective was to build a theory of the dynamics of inter-organizational knowledge creation that attends to the importance of ICTs in affecting project governance. The case study leads us to formulate the following conjectures: (1) in project contexts, firms that maintain highly congruent object worlds and a strongly embedded common ICT platform enjoy a higher degree of information pooling and therefore can jointly create knowledge despite decreased physical interaction; while (2) in project contexts, firms with incongruent object worlds or with congruent object worlds lacking strongly embedded common ICT platform demand a higher degree of physical interaction to jointly create knowledge. We also derive a dynamic model of the evolution of inter-organizational governance and the role of ICTs in this evolution. The model shows how the ways in which ICTs are embedded into design activity can vary across project stages and consequently influence the shape of those relationships.

The remainder of the paper is organized as follows. Next, we will review literature pertaining to the use of ICT in inter-organizational knowledge creation and the concept of object worlds. We then will present our method and data sources. We continue with three illustrative data vignettes, which are each followed by a summary interpretation in light of our framework. We conclude by discussing our findings generally and observing implications for research and practice.

Inter-organizational knowledge creation and information technology

Large-scale and complex design activity is both knowledge intensive and generative, and is therefore highly uncertain and unpredictable. Thus, design activities are difficult to contract explicitly, and may encourage opportunism—and have been traditionally expected to be carried out within hierarchies (Coase, 1937; Williamson, 1985). Nevertheless, in recent years such activity has become increasingly common between firms (Argyres, 1999; Helper *et al.*, 2000; Boland *et al.*, 2007; Taylor and Levitt, 2007). Several reasons account for this: increased demand for flexibility, benefits of economies of scope, growth of regions with unique design skills (e.g. fashion), and growing diversity of the type of knowledge required to finish the task (Katzy *et al.*, 2000; Berente *et al.*, 2007). In addition, ICTs have enabled new arm's length market forms of inter-organizational governance as they reduce the cost of design transactions and facilitate better control of opportunism (Malone *et al.*, 1987; Choudhury, 1997). Consequently, inter-firm organizing in terms of 'projects' has become increasingly popular and promises to be more so in the future (Gann and Salter, 2000). While recently there has been a greater emphasis on key challenges associated with ubiquitous inter-organizational projects (e.g. Sydow *et al.*, 2004), including how organizations can capture knowledge created during such engagements (Brady and Davies, 2004; Bresnen *et al.*, 2004), there is limited exploration of forms of governance that drive successful inter-organizational focused knowledge creation. Thus governance of project forms is an area that could benefit from more attention (Scarbrough *et al.*, 2004;

Harty, 2008). To ground such study in the broader discourse on organizing, we turn next to the body of literature that emphasizes relational forms of inter-firm governance.

Over the past two decades, organizational theorists have shed light on the significance of *relational* forms of governance—a 'hybrid' or 'middle-ground' alternative to pure market or hierarchy (Dyer and Singh, 1998). Such forms are organized around 'networks' (Powell, 1990; Powell *et al.*, 1996) and involve embedded social relationships characterized by reciprocity and trust (Granovetter, 1985; Uzzi, 1997). These forms include joint ventures (Inkpen and Dinur, 1996), 'pragmatic collaboration' across supply chains (Helper *et al.*, 2000; Sabel, 2004), and inter-organizational cycles of cooperation and conflict during innovation (Ring and Van de Ven, 1994; Van de Ven *et al.*, 1999). Relational scholars argue that network-like governance forms are erected by elevated levels and forms of information sharing—what we call *information pooling*, as well as co-located, synchronous, face-to-face, interpersonal practices—what we call *physical interaction* (Table 1). From a theoretical perspective, different types of *information pooling* and *physical interaction* form necessary elements in any knowledge creating activity (Nonaka, 1994; Cook and Brown, 1999). Cook and Brown (1999) characterize this as a 'generative dance' between explicit knowledge sharing (i.e. *information pooling*), and tacit knowing-in-practice (i.e. *physical interaction*). Next we address each of these concepts in turn.

Information pooling

We define 'information pooling' as the level to which project-related information, explicit knowledge and proprietary information are made readily available across participating organizations and actors. It refers to more than sharing narrow explicit product information, or electronically integrating transaction data across organizations (Malone *et al.*, 1987). While such information sharing is a prerequisite to successful inter-organizational knowledge coordination, researchers also indicate that less explicit information such as plans and 'perspectives' (Helper *et al.*, 2000) must be shared for knowledge creation. We can accordingly establish a continuum from strategic information sharing on the one hand, to pooled information sharing on the other hand. Strategic sharing involves a highly competitive, narrow band of information sharing such as that associated with price information, whereas pooled information sharing involves completely open, trusted information sharing associated with long-term, close-knit relational networks.

Physical interaction

We define 'physical interaction' as the extent of regular, collocated work practices involving face-to-face interactions among organizational members during design activity. Forms of regular, proximal interpersonal interaction are typical in many inter-organizational knowledge creation activities that involve tacit knowing-in-practice (Cook and Brown, 1999). Knowledge embedded in these activities is difficult to transfer discursively and without co-located interaction (Nonaka, 1994). Research into project forms of organizations has also found that frequent face-to-face interaction is instrumental for effective project outcomes (Sapsed and Salter, 2004; Scarbrough *et al.*, 2004). We can accordingly create a continuum for the intensity of physical interaction—from limited to frequent.

We can now distinguish between two situations of inter-organizational governance in terms of knowledge

Table 1 Practices associated with inter-organizational knowledge creation

Relational knowledge creating practice	Definition	Source terminology	Source
Information pooling	The level to which project-related information, explicit knowledge and proprietary information is made readily available across organizations	Information pooling	Powell (1990); Helper *et al.* (2000)
		Information transparency	Dyer and Singh (1998)
		Fine-grained information transfer	Uzzi (1997)
		Strategic integration	Inkpen and Dinur (1998)
Physical interaction	Regular collocated practices among organizations during a joint knowledge creating effort	Regular patterns of inter-firm interaction	Dyer and Singh (1998)
		Joint problem solving arrangements	Uzzi (1997)
		Personnel transfer, frequent meetings, physical visits	Inkpen and Dinur (1998)
		Frequent face-to-face meetings	Helper *et al.* (2000)
		Pooling people together	Powell (1990)

creation potential: (1) those that are concerned specifically with knowledge creation between companies, which we describe as 'governance for innovation' (Figure 1, second column—frequent interactions), and (2) those that are not concerned with new knowledge creation—called 'governance for coordination', which is knowledge creation for coordination (Figure 1, first column—limited interactions). Prior research indicates that typically the former will involve higher forms of *physical interaction*, as it is informed by the epistemology of practice (Cook and Brown, 1999). The latter involves either arm's length market transactions of exchanging products or well-defined knowledge, and related relational transactions that can be supported by formalized information technology (e.g. Electronic Data Interchange—EDI). Likewise, we can distinguish between two situations of inter-organizational governance in terms of the level of information pooling: (1) those that are concerned specifically with information pooling (Figure 1, first row—pooled information sharing), and (2) those that are not (second row—strategic information sharing). Overall, we can formulate a stylized framework as depicted in Figure 1 to represent four alternative forms of inter-organizational governance based on their level of physical interaction and level of information pooling allowing for different forms of inter-organizational coordination and knowledge creation. Next, we will briefly discuss each quadrant.

(1) *Arm's length governance (strategic information sharing; limited interaction)*: In such traditional 'arm's length' market transactions physical interaction is kept minimal and most information is built into pricing mechanisms and made explicit through contracts (Dyer and Singh, 1998). In such forms there is no explicit concern for joint knowledge creation other than that related to transactions and their conditions and framing (e.g. contracts and their enforcement)—the knowledge shared serves to regulate effective inter-organizational coordination. ICTs involving online retail of well-defined products (such as Amazon.com) would be examples of technologies that can support arm's length forms of governance and related knowledge sharing. Another example would be those technologies that match products to customers based solely on explicit product and customer information (i.e. Malone *et al.*'s (1987) 'brokerage effect').

(2) *Relational well-understood activity (information pooling; limited interactions)*: While inter-firm knowledge creation is expected to require some form of relational governance, a great deal of relational activity does not necessarily create new knowledge. For example, interpersonal relationships and related 'weak links' are often cited as reasons for straying from the strict arm's length discipline assumed by transaction-cost theory and generate new forms of interactions (Granovetter, 1985). Information systems literature has also addressed relational forms by analysing activities where joint knowledge creation is not the primary goal (e.g. Grover *et al.*, 2002; Schultze and Orlikowski, 2004; Malhotra *et al.*, 2005). To this end, research has probed social processes that are 'embedded

Physical interaction (Action)

Information sharing (Explicit)		Limited	Frequent
	Pooled	2. Relational well-understood activity (IOS Research; Granovetter, 1985)	4. Relational knowledge creation (Helper *et al*., 2000; Dyer and Singh, 1998; etc.)
	Strategic	1. Arm's length traditional market (Williamson, 1985)	3. Early stage knowledge creation (Van de Ven *et al*., 1999; Ring and Van de Ven, 1994)
		Governance for coordination	Governance for Innovation

Figure 1 Inter-organizational governance framework for knowledge creation

in standard and well-specified protocols' (Malhotra *et al.*, 2005, p. 150). In this line of research, ICTs adopt the role of a relational asset such as EDI applications, which support richer information pooling associated with explicit, well-understood transactions in specific segments of inter-organizational activity (e.g. Bensaou, 1997; Choudhury, 1997). Therefore, ICTs can expand market-based transactions through elevated information sharing and less costly, more accurate and timely communications. This is consistent with Malone *et al.*'s claim (1987) that information technology enables 'hierarchical transactions' to be carried out within the markets due to electronic integration and communication effects.

(3) *Early stage knowledge creating activity (strategic sharing; frequent interactions)*: While relational theorists indicate that both information pooling and physical interaction are necessary for inter-organizational knowledge creation, they remain ambiguous how these elements came into being. In fact, some scholars argue that high degrees of information pooling are not necessary during early stages of knowledge creating effort—only frequent interactions (Ring and Van de Ven, 1994). Information sharing can remain highly strategic in those stages while working understanding of the other is being developed and organizations build up trust (Ring and Van de Ven, 1994; Van de Ven *et al.*, 1999).

(4) *Relational knowledge creating activity (information pooling; frequent interactions)*: Several scholars argue that in order to create knowledge jointly, firms need to engage in high levels of information pooling combined with elevated levels of physical interaction (Nonaka, 1994; Cook and Brown, 1999). Information systems research is nearly void of research into such forms of inter-organizational knowledge creation. What little exists, in fact, contradicts this claim. For example, Argyres (1999) reports a design activity that had a high degree of information pooling, but a limited physical interaction due to the clever use of information technology. Likewise, in Majchrzak *et al.*'s (2000) study frequent interactions ensued outside of the system, while the amount of information pooling was less than expected. Yet, in both cases the projects were highly innovative and the designs were hailed as a success. Overall, we recognize that the form of governance alone does not explain the level of inter-organizational knowledge creation in some contexts.

Because knowledge creation cannot be explained solely by the form of governance we explore other mechanisms affecting the differences in the knowledge creation outcomes. As ultimately knowledge creation involves interactions between individuals and their cognitive processes, we augment the form of governance with the socio-cognitive nature of group understandings and cognitive practices involved in knowledge sharing. To this end we adopt the idea of an 'object world' (Bucciarelli, 1994) to distinguish between designers' cognitive practices on a basis of the congruence of their design practice with regard to the artefacts they use. Taking this approach allows us to explore the combination of inter-organizational governance and socio-cognitive mechanisms that jointly influence knowledge creation.

Object worlds

An individual engaged in joint knowledge creation is typically some sort of designer. In the case of joint knowledge creation among firms, several separate disciplinary specialties must be assumed, as this is the ultimate reason for engaging in the joint design. If the required knowledge existed within an organization, it is unlikely that the inter-firm design collaboration would be necessary. As such this creates difficulties in knowledge creation not only across firm boundaries, but also because of differences in design practices and challenges to perspective making and taking in such settings (Boland and Tenkasi, 1995). Thus, it has traditionally been common practice to stratify organizational actors by functional groups (e.g. Lawrence and Lorsch, 1967): members of the same functional group tend to have a similar 'emotional and cognitive orientation' (Lawrence and Lorsch, 1967, p. 11). More recently, other concepts such as communities of practice (Brown and Duguid, 1991) have been used to demarcate groups that have a similar emotional and cognitive orientation and where community knowledge is constructed cooperatively.

Yet, differences between functional or disciplinary based communities are not the only criterion by which designers differ—even designers within the same specialty can inhabit vastly different 'object worlds' (Bucciarelli, 1994). This requires us to distinguish between cognitive and emotional orientations on a richer basis. In this regard an 'object world' describes the unique, personal context within which a designer engages in the practices of design. This object world is made up of physical artefacts, tools and instruments, as well as abstract formalisms, design principles, methods and associated practices. Object worlds form a fixed background in the sense that they permeate and support all design activity, but while a designer learns, object worlds 'are given new expression and show a different nuance from one design task to another' (Bucciarelli, 1994, p. 81).

The concept of object worlds acts as an important sensitizing device in analysing information technology's role in complex design projects for the single reason that object worlds vary in their congruence with each other. Incongruity of object worlds creates problems in communication—even among designers of the same discipline (Bucciarelli, 1994). Therefore, since information technologies and related artefacts form a fundamental element of the designer's object world, local adaptations of information technologies can have dramatic effects on a designer's ability to share knowledge. For example, designers using different systems or even different versions of the same computer-aided design application (CAD) experience heightened communication hurdles.[1] Designers running even the same CAD system often experience problems in knowledge sharing when their local technology adaptations—i.e. level of customization, design standards and use patterns differ significantly. By aligning the object worlds of participating designers we would expect knowledge sharing to take place more smoothly (Bucciarelli, 1994). However, in complex, inter-organizational design activity such a situation is difficult to achieve, if not unlikely. So rather than assuming a complete alignment, we can conceive of more or less congruence between object worlds, which can be evidenced by the nature of primary design artefacts that are embedded in that design activity.

In order to be embedded in collaborative design activities, information technologies must enable what Malone and associates (1987) describe as the 'communication effect' and the 'integration effect'. The communication effect denotes fast and inexpensive electronic communication of explicit information, whereas the integration effect describes an interpenetrating process. In order to reduce physical interaction associated with inter-organizational knowledge creating activity, object world congruence is necessary, but not sufficient, for such outcome, as such congruence will facilitate only the communication effect. In order to reduce physical interactions, the ICT capability must also be embedded in the object worlds, of the designers generating 'intregration effect'. Under these conditions one might be able to reasonably anticipate a greater likelihood of joint knowledge production without physical collocation.

Research aims and questions

Overall, per our discussion we can formulate the following research questions related to inter-organizational knowledge creation:

(1) In what way do differences in object worlds as constituted by their differences in use of ICTs support inter-organizational knowledge creation?
(2) Under what conditions do distinct information sharing practices—information pooling or physical interaction—contribute to inter-organizational knowledge creation?
(3) What is the relationship between different levels of object world congruence, the variety of information sharing practices, and knowledge creating design activity?
(4) What is the significance of object world and information sharing practice differences over the course of a single project, or between projects?

We will next report a case study where these questions were examined in depth.

Research method

Case selection

We investigated an architectural project carried out by Gehry Partners to address the above questions. Gehry Partners is one of the leading architect offices in the world known for bold designs such as the Guggenheim Museum in Bilbao and the Walt Disney Concert Hall in Los Angeles. For this study, we chose to focus on Gehry's work on the Peter B. Lewis Building at Case Western Reserve University (Figure 2). The case study represents a revelatory case involving an effort to abstract from grounded, case observation a theoretical model that can be later applied and tested in other contexts—what Yin (2003), describes as analytic generalizability.

The project consisted of a radical architectural design and a shift to 3D (from 2D) computer-aided-design (CAD) technology across participating design teams. Our purpose was to explore this technological shift and the associated interactions among several design firms involved in the project to better understand the levels of information pooling and physical interaction and their interactions with object world congruence.

This study forms part of a broader longitudinal research project undertaken to study the practices of Gehry Partners with a focus on innovation and the role of new ICTs on the AEC industry (see Yoo *et al.*, 2006;

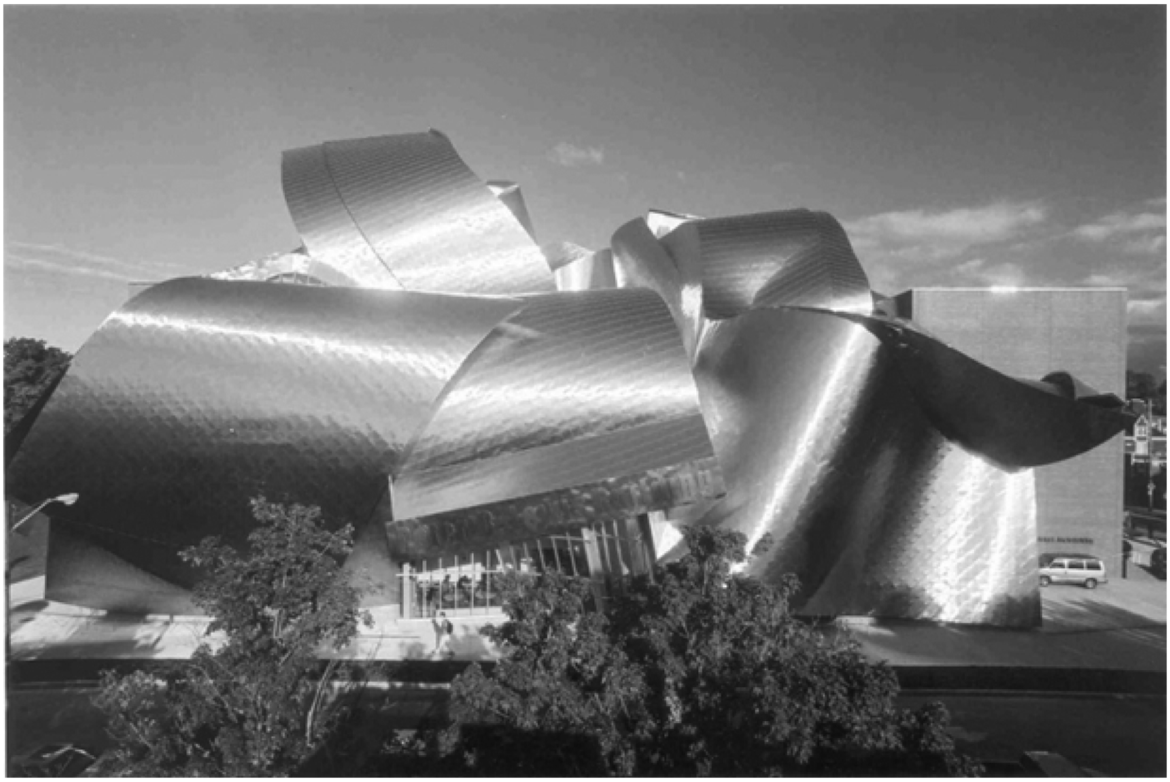

Figure 2 Peter B. Lewis Building at Case Western Reserve University

Boland *et al*., 2007; Gal *et al*., 2008).[2] The construction industry is a particularly suitable context for the study of inter-organizational knowledge creation and relational forms of governance because of the prevalence of relational, project forms of organizing in the industry (Bresnen and Marshall, 2000; Yoo *et al*., 2006; Taylor and Levitt, 2007), and the increased focus on innovation (Winch, 1998; Harty, 2005; Boland *et al*., 2007). At the same time Gehry's designs are often so radical in scale and scope as to pose a risk of being infeasible for the construction—especially given the demands for reliable cost and timing estimates. In generating knowledge to address these challenges, Gehry Partners must therefore interact with a diverse, fragmented industry with a tradition and norm bound culture of coordinating their activities with traditional knowledge bases in risk adverse ways. As a result, their design projects must draw upon diverse and varying sets of expertise and trades that have worked closely together to produce Frank Gehry's radical designs. The firm has therefore developed a reputation for designing and successfully leading highly innovative construction projects where each project combines multiple firms, and diverse design knowledge in a plethora of inter-organizational configurations at different locations, and across time (Yoo *et al*., 2006). Because Gehry's buildings are difficult to envision using traditional 2D technologies, in the early 1990s Gehry began to use highly sophisticated 3D CAD (i.e. CATIA™) software developed for the aerospace industry and widely utilized in automotive and shipbuilding (Baxter, 2008). Therefore, Gehry requires that contractors purchase and become trained on an advanced three-dimensional CAD systems, and will use the system as the single master source to which they refer in their construction tasks. In general Gehry Partners has embedded CATIA and other ICT tools deeply into their design practice thus changing their 'object worlds' (Yoo *et al*., 2006; Boland *et al*., 2007). Overall, we found this case to be a suitable data source to explore the relations recognized in our research questions as outlined in Table 2.

Data collection and analysis

The data were collected primarily through open-ended interviews using a semi-structured questionnaire near the end and shortly after completion of the building. The general theme during data collection was to explore how the participants were impacted by the Gehry project and how did the use of 3D CAD as the primary design and informational reference for building affect their design activity. The interviews focused on the participants reflecting on and recalling

Table 2 How the Gehry Partners project fits with research questions

Research questions	Gehry fit with research questions
1. In what way do differences in object worlds of designers, as constituted by their differences in use of ICTs within their practice, support inter-organizational knowledge creation?	• In the Gehry Project study we expect to encounter differences in CAD technologies from 2D, 3D, and among 3D platforms. These represent differences in key aspects of their object worlds.
2. Under what conditions do particular information sharing practices—information pooling or physical interaction—contribute to inter-organizational knowledge creation?	• The AEC industry is characterized as a loosely coupled, decentralized, project-based industry. However, Gehry's projects are known for being more tightly controlled and utilizing 3D CAD as a central information repository. • We expect knowledge creation to take place as a result of interactions among designers, engineers and contractors as they attempt to come up with designs and construction methods to meet Gehry's radically designed shapes.
3. What is the relationship between different levels of object world congruence, the variety of information sharing practices, and knowledge creating design activity?	• We expect that we will be able to compare and contrast in various episodes how different firms interact, share, and utilize CAD technology to create knowledge.
4. What is the significance of object world and information sharing practice differences over the course of a single project or between projects?	• We expect that we can compare firms that have different experience levels working on a Gehry project to determine if there is any notable difference in information sharing practices (i.e. pooling levels and physical interaction levels) and object world congruence (i.e. 3D CAD experience).

key areas of difference in this Gehry project compared to their vast experiences with previous 2D, non-Gehry Partners projects. With those participants that had previous Gehry experiences interviewers probed to also understand differences between various Gehry projects. Interviewers probed these differences to understand their significance to the participants as well as the probable impact on the firm or industry as a whole.

Interviews were transcribed and sent to interviewees for content validation. The transcripts were then organized and analysed using ATLAS.ti™—a computer assisted qualitative data analysis software package. Our analysis purposefully focused on firms with highly innovative responsibilities in the construction phase of the project—namely the general contractor, concrete subcontractor, interior framing and drywall contractor, and metal roof subcontractors. It is no surprise that these areas had both substantial design and constructability challenges given Gehry's undulating and curving design. The analysis of the data proceeded by reading and re-reading interview transcripts with the purpose of identifying key facts, the flow of the project and significant illustrations of the participants' perceptions of key differences and changes. After such initial analysis and open coding more specific analysis and re-reading was carried out focusing on situations in terms of knowledge creation, aspects of object world congruence, and indications of the level of physical interactions and information pooling. The authors iterated through these analyses multiple times and compared findings to ensure that the examples and episodes were tightly grounded and consistent with the individual firm, the project as a whole, and where applicable with pre- or post-Gehry projects in which the firms may have been involved. These analyses were then subject to scrutiny from other project team members to ensure faithful representation and interpretation of the data for theory generation.

Project overview

In the design of the Peter B. Lewis Building a mix of both locally and nationally based contractors and trades were assembled for the project. While some of these organizations had worked with Gehry Partners in the past, many were working with Gehry's office for the first time. We focus on the design and implementation of three key elements of the building, which involved high levels of inter-organizational knowledge creation and coordination: (1) framing and drywall; (2) metal roof design; and (3) concrete casting. Architects typically work through a general contractor or construction manager who manages and coordinates their activities with the subcontractors, and Gehry Partners is no different. For this project, the general contractor was Hunt Construction that had not previously worked with Gehry Partners. Figure 3 illustrates a simplified version of the inter-organizational coordination structure.

Typically, AEC projects are fairly sequential. In the 'pre-construction' phase, the architect completes the

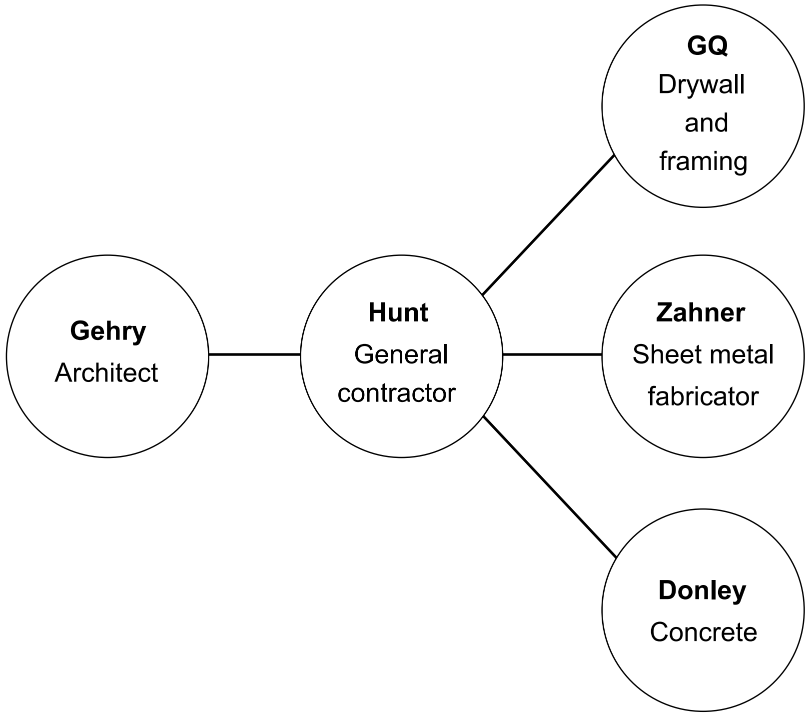

Figure 3 Subset of Gehry's inter-organizational structure for the Peter B. Lewis Building

design, takes care of contractual arrangements with contractors and subcontractors, and prepares to construct the building. This is followed by a bidding process where subcontractors analyse piles of two-dimensional drawings and specifications in order to estimate the pricing and timing for completing the job. Once the final subcontractors are determined the general contractor will compile a set of contracts based on the 2D information. In the 'construction' phase, the architect is generally more removed, occasionally answering questions or clarifying items that were not specified, but significant design activity is usually long complete. Inter-organizational communication is typically done through highly standardized documents, such as two-dimensional paper drawings and specifications, and requests for information and clarification. Often this communication can take the form of digitized CAD documents shared by different groups (AutoCAD™ is the de facto standard package).

While different AEC projects reflect this simplified phase structure to varying degrees, Gehry Partners did not adhere to such a linear sequence in the Peter B. Lewis project. In contrast, in the pre-construction phase Gehry Partners engaged many trades and contractors in what they refer to as 'design assist', where subcontractors can give their input and increase their understanding of the constructability. While pre-construction involvement is not new in this industry, Gehry's level of commitment and openness to involve contractor organizations in creating new knowledge is quite unique. In addition, throughout the whole project, Gehry made an effort to collaborate intensely with each firm as it changed its designs—often even during the construction phase. Next, we will present three episodes that illustrate mechanisms employed to foster knowledge creation in terms of information pooling and physical interaction. We will first describe the vignette of the episode and then interpret it in the light of our model and research questions.

Three design episodes in the Peter B. Lewis Building

Episode 1: Design assist to develop new concepts of internal framing

The vignette of the episode

GQ, the internal framing and drywall contractor was introduced to the project during the design development phase and began to estimate the cost and timing for the framing and drywall based on 2D drawings and physical models. According to Gehry Partners they intentionally withheld more sophisticated 3D CAD representations early in the process:

> … normally wouldn't want to show any computer data to somebody who does drywall because they'll just

> double their price. And the logic will be, well if you need all of that, this must really be hard. So there's a cultural barrier depending on where you are in the trade. (Interview with a partner from Gehry Partners)

This didn't mean that GQ did not eventually use 3D, rather it was a strategic process by Gehry to prepare them for acceptance of the 3D technology by making it appear more useful to GQ's practice. Accordingly the same partner from Gehry noted that:

> … you have to be very careful how you present the information because the first reaction could be, this isn't going to help me. This building must be really difficult … And we used to do that a lot in the early days. And we realized if we show it to them now, they're going to see it as a problem. If we … let them get in trouble and then we'll get them out of trouble with it and they'll adopt it and that, you'll see that change during the course of a project. (Interview with a partner from Gehry Partners)

3D CAD was introduced to GQ later, but the 3D model provided by Gehry did not contain all of the details of how to assemble the framing members. Therefore, GQ had to work collaboratively with Hunt and Gehry Partners to complete the design:

> I mean, literally, Frank Gehry on the drywall gives the film of paint on surface, that's all he gives. He didn't give us the framing conventions. We had to go back that system up with a frame in. He told us that it had to be a 6' stud, but he didn't tell us where to put that 6' stud, and it's our responsibility to locate that stud, and to create the methods to actually physically do it in the field. And that's where a lot of our innovation, and our creation, and that was done … (Manager at General Contractor, Hunt Construction)

3D visualization was essential for them to cooperatively design, test and eventually decide on a framing method. It contained the necessary connections to other system components to evaluate the impact of proposing alternative framing methods. While Gehry did provide an initial *framing concept* to suggest a way to develop the internal framing system, it was not robust enough (as judged by GQ) to be used for the complex and undulating surfaces. The initial concept involved bending the studs to make the curves, which was later determined to be altogether infeasible. As an alternative, Hunt and GQ worked with a 3D consulting specialist (provided by Gehry) in Hunt's offices and they jointly came up with a framing concept. The collaborative process involved working in 3D CAD to understand the shapes and apply and understand the constructability of the newly proposed framing concepts. Over the course of eight months they evaluated various concepts by modelling them in 3D and then doing physical mock-ups and tests in the field. The form of collaboration not only involved visits by a representative from GQ to Hunt's

Figure 4 Drywall of the Peter B. Lewis Building

and Gehry's offices, but also meant coordinating with GQ's team of personnel that would actually use their new framing method in the field. GQ's project manager described how it worked:

> All the binders and binders of paper went out to the field because you got to bring it back to what they're used to. And that's 2D. So I had to bring it back to them in that form. It was really something, as I would go to California, I'd spend 4 or 5 days, I'd come back and I'd have this whole group of guys on the job just starving for information, and just dragging me over to the computer. … And then they'd tell me what I did wrong, then what I did right. And then they would try to take the AutoCAD work and relate it back to what was in CATIA. It was really difficult. Very difficult.

In reflecting upon the unusual nature of design collaboration and interaction, the GQ manager noted how much different this process was compared to his previous 20 years of experience:

> I have never, ever spent more than an hour in an architect's office prior to this job. And I spent 22 trips, 4 and 5 days at a time in their office. And I mean I've spent some days in there where I was in there at 8:00 in the morning and I didn't get out of there until 10 or 11 at night, working on this frame.

Ultimately, they decided on a process which involved extracting data from 3D CAD to 2D CAD and then sending this information to computer numerically controlled (CNC) equipment to cut the appropriate sizes and shapes. They attempted to maintain the framing members to standard sizes which could be shipped and assembled in a way that eased the transition for those doing the construction in the field.

Interpretation

The above vignette illustrates the involvement of GQ, a subcontractor with no previous experience in 3D CAD, within Gehry's design assist process. As GQ's project manager indicates, his team is accustomed to working with 2D drawings. They are on unfamiliar ground in being so significantly involved in the design assist, pre-construction process, and they certainly have never used a powerful tool like CATIA™. Their object world is quite different from Gehry's team, and it appears that with limited, strategic information pooling, and highly frequent physical interactions, a suitable environment was created for jointly developing and prototyping new knowledge for the framing and drywall processes.

What is striking about this example is the frequency of physical interaction required to come up with the new framing solutions, and the strategic way in which Gehry Partners doled out access to the pooled information. This example offers an insight that when new partners engage without the initial capability for information pooling, pooling of perspectives and plans (Helper *et al.*, 2000) is an important preliminary step. It also indicates that there was a need for a great deal of frequent physical interactions to accomplish the design. The increase in physical interactions was not only among firms (e.g. GQ, Hunt, Gehry and specialist 3D consultants), but also within the GQ firm among more experienced designers and foremen with carpenters. Lastly, the system of interactions described in framing development was more than simply transforming information from 3D to 2D, but more importantly involved the development of mutual understanding between the new framing concepts and how to incorporate them into their 2D practices in the construction field thus evolving the object worlds of the design team.

Episode 2: Pooling multiple perspectives for undulating roofs

The vignette of the episode

The design and installation of the undulating stainless steel roof on the Peter B. Lewis Building involved the collaboration between Gehry Partners, the architectural metal designer, Zahner corporation, and the metal envelope contractor Crown Corr, Inc. While Zahner had significant experience with Gehry, this was only the second Gehry project for Crown Corr.

Zahner, the metal fabricator of the roof for the Peter B. Lewis Building had worked on over 20 projects with Frank Gehry since 1987. During this time Zahner's design and fabrication process has evolved significantly in their use of sophisticated 3D technology. Over the years the Zahner and Gehry relationship has been mutually beneficial. As Zahner has expanded its capability by striving to fulfil complex aspects of Gehry's designs, Gehry has later incorporated Zahner's new capabilities in subsequent designs. Zahner has clearly bought into the idea of having a single 3D master model. This puts Zahner and Gehry on the same page, so to speak:

> It's in the building industry to me, and I've stated it several times, that it's a real potential to bring the designer back in as the master builder. If he does a parametric model, then he's brought all the pieces together. And I saw how it worked on EMP [Experience Music Project], if there was ever any question… We'd immediately go to the [3D] model and see. (Interview, William Zahner)

While Zahner made good use of the CATIA™ 3D model to design the patterns and approach to the roof, they also had to consider that they would be handing off the installation aspect on the Peter B. Lewis

Building project. Their strategy in this project was to reduce the variability and degree of customized pieces in the roof. Reducing variability in roof pieces meant that the installers would not have to worry about fitting customized shingles in precise locations and angles, but they would have to have a good understanding of how the whole roofing system would flow by using more standardized pieces. Zahner describes this system here:

> We simplified it. If Zahner was doing it, we would have made that a little cleaner because, but we knew that somebody else was installing it, so we made it okay, how do we make this simple and make it still look good for Frank Gehry, cause that's where your eye's going to fall. Your eye is going to follow those edges. So we simplified it so the cut … That's the way it was done in the field. (Interview, William Zahner)

Zahner sacrificed some level of precision because of the complexity involved in handing off the metal roofing to a different installer. Despite the efforts for simplicity, the task still proved difficult. Crown Corr manager, Greg Husarik commented on working together to figure out how to install the metal roof:

> Whenever we ran into a problem, we worked together to figure to find the solution. That was the only way to do it. It wasn't like some jobs where the architect designs it and you have to duplicate it exactly as drawn. This job was just so complicated and unlike everything else, that we had to make some things work. All in all, the architect on site was happy with what we came up with. It turned into a big love fest … (Bas, 2001, direct quote of Greg Husarik of Crown Corr)

> Occasionally there was a dramatic 'Oh my God!' when materials or sight lines didn't line up. There was little in the way of printed blueprints or documents to consult. Instead, it was back to the computer screen, back to CATIA—which was fortunately always right, never wrong, and eventually allowed for any quirks to be worked out. The alternatives could have been disastrous. (Bas, 2001)

Crown Corr were informed early by the general contractor that they would need to be familiar with CATIA™ and how to use it. Crown Corr's use of CATIA™ was required according to Hunt, the general contractor. Compared to traditional AutoCAD™, CATIA™ allows for tighter tolerances, well beyond what is likely achievable in a building project and more suitable for aerospace of automotive applications. Recognizing the need to carefully coordinate the intersection of complexly curved shapes, Hunt emphasized the need to be within these tight tolerances on the roof. This resulted in significant difficulty, initially, at installing the roof shingles:

> We drove tolerance so hard … that when it came to the shingle installation, these guys [Crown Corr] were getting so precise about the layout of the shingle on installing it, in fact we had this two-person crew one day that got a total of four shingles put up … what we realized … is that it was, it basically boiled down to smooth and flowing and just as long as you knew that the shingle pattern wasn't going to unfold on you, when you got to the top and get your drainage pattern screwed up, … once we got through some trial and error, put some shingles up, had to take 'em off, there was a way of being able to put shingles on the building in a very fast method. (Hunt Construction Manager)

Interpretation

The above episode illustrates complex information pooling in several ways. First, Zahner relies significantly on the master model (CATIA™) to design and implement architecture. This allows them to understand complex interrelationships in the building components as a result of design changes or further development. Zahner and Gehry have formed an interesting inter-organizational joint knowledge creation process that is more evident over the course of their continued relationship as opposed to one single project. We developed this interpretation by focusing not only on the Peter B. Lewis project but on Zahner's broader perspective dating back to 1987. Thus, as Zahner's capabilities advance, Gehry is able to both take advantage of these and push Zahner in different ways. What is particularly striking is the limited physical interaction as well as the limited explicit design information exchange that seems to exist at this stage between Gehry and Zahner. This can be contrasted with the frequent interaction apparent in the relationship with Crown Corr—the organization that does not have the related experience and aligned object world.

The master model allows Zahner to develop ideas by simulating and understanding complex interrelationships without as much frequent interaction with Gehry. As a result of their experience with Gehry's practices, and their long-standing adoption of CATIA™, one can assume that the object worlds of designers are fairly aligned or at least well understood—certainly with respect to the primary design tool, CATIA™. Consequently, it is worth pointing out the very high degree of information pooling with lower collocated physical interaction.

Episode 3: New terminology for reshaping concrete

The vignette of the episode

Donley Inc., an experienced engineering and construction firm specializing in concrete work was invited to the project by the general contractor, Hunt

Construction. The development of precision concrete required in a complex project like this was extremely difficult. As the concrete portion of the project was critical—many of the exterior wall elements involve curving concrete wall covered by red brick—there was necessarily a greater consideration of it during the early phases of a project when the design was being explored and subject to more changes.

The complexity of the project was magnified as the designs evolved and changed more frequently earlier in design as well as during the course of construction. Challenges arose from the difficulty in modelling changes and their implications for structural design changes, the process of forming up the forms and the actual placing of concrete. A key assumption for concrete work is that concrete formwork is standardized, and is intended to be reused on multiple jobs resulting in significant cost savings. The standardized formwork also uses standard and repetitive methods for the set up and configurations in traditional rectilinear shapes.

The complex and unusual 3D freeform shapes challenged these conventions, obsolescing many of them and necessitating the use of customized concrete forms. Changes in a conventional rectilinear design shape can easily be accounted for without affecting the concrete formwork method and processes. However, changes in complex and unusual shapes can result in the significant rework of already unique concrete form shapes. One of Donley's managers described how making changes to complex walls was more complicated than with flat walls:

> … it's much easier to switch gears because it's flat, okay. Now when you're getting something that wall's evolving where they go into the model and they tweak a few things here and there, it makes a difference in what you did with formwork process and your design, cause you have to go through many different screens of grabbing information to develop your formwork … now you change it a little bit this way or this way, you've got to go back through all the processes of extraction the points in order to do that formwork design again.

In addition to dealing with the design changes, Donley's main challenge was how to accommodate 3D complexity and then translate that into a process for those working in the field. Like GQ and Zahner, Donley was involved in the Gehry design assist process, but had a different interpretation of that process. They did not see their early involvement as designing and joint knowledge creation, but rather they sought to solve constructability issues and determine the possibilities of concrete application given certain design considerations. This is the standard perspective that Donley and most subcontractors carry on to their pre-construction design activity as indicated by the following comment from a manager at Donley:

> We were looking at the model, we were looking at 3D AutoCAD extractions during the pre-construction process, but until the model was complete and we got the actual 3D extraction through supplemental PRs and information from Hunt through Gehry that we were able to do our formwork design at that point. (Interview, Manager at Donley)

Figure 5 Concrete geometry of the Peter B. Lewis Building

Through the pre-construction engagement Donley's awareness of the complexity of the project increased, that the project was still evolving and that 3D representations would become essential for their concrete work—something that they earlier thought they might avoid:

> Yeah, initially we hadn't planned on using that much 3D, but as the pre-construction evolved, it became pretty clear that 3D AutoCAD and 3D AutoCAD extractions out of CATIA were going to be needed in order to build the structure. And it was the only way to build it … to build all your ruled and curved surfaces … but building any of the ruled surfaces and curving surfaces, we definitely needed the 3D AutoCAD, and that came to light as the preconstruction process evolved.

Donley was told by both Gehry and Hunt that they did not need to adopt the same 3D software, CATIA, but that extractions from CATIA imported into 3D AutoCAD would be sufficient. However, this decision would prove to be a significant technical challenge in pooling information. Using the 3D data, the engineers designed the uniquely shaped forms and methods for shimming the forms to create the appropriate curve. The placement of shims to achieve the appropriate curve was done in 3D and at points extracted into 2D printouts of the final location for the field carpenters to put the shims in place. The concrete forms were represented in detailed shop drawings which specify where the forms are placed and how to make them so that they would create the proper shape. The formwork engineer used 2D and 3D drawings with written descriptions in the formwork shop drawings. The set of shop drawings contained 3D visual information (e.g. 3D screen shots from AutoCAD) as well as precise 3D coordinate descriptions.

These processes of coordination between the formwork engineer and the carpenters in the field were not straightforward and required frequent interaction to clarify what was in the shop drawings. These frequent interactions resulted in the formwork engineer learning from those assembling the forms so that he could better design knowing the constraints in the field. As he put it the carpenters in the field would say:

> 'Hey, you know you can't bend a three-quarter inch sheet of plywood that way, you can only bend it this way and this way and so forth.' And you don't know that in AutoCAD or anything when you are drawing it you just hope for the best. (Interview, Formwork engineer)

Field carpenters also learned to interpret and understand the 3D drawings and associated terminology so that they could share any problems with the formwork engineer when following the shop drawings.

> They learned from the drawings and they learned the lingo and the communication on it. So they could call up and say, 'hey, you know you're so many degrees off here from your coordinate.' For awhile there we actually developed a new terminology or a new communication process on the job where we educated them, and they educated us. (Interview, Formwork engineer)

Occasionally, the difficulty in communicating between the field carpenters and the designers resulted in the need to interactively use CATIA™ on the job site as a visual aid for resolving misunderstandings as noted in the following excerpt:

> I'm sitting in Hunt's trailer, we're looking at the screen, and there's this little sliver of concrete that needed to grow on the edge of one of the curved walls … Anyway, there was some reason it had to be there, and there was no way for me to explain it to this guy. So I went up on top deck and grabbed Don, our carpenter foreman … he's looking at this things and he's like, 'do we have to do this? [laughter] Is that absolutely necessary?' And of course it was …

As noted earlier, a major challenge faced by Donley was responding to the changing designs. This was further compounded by discrepancies resulting from inaccurate and out-of-date extracts from the CATIA model. Donley noted that many times issues that they saw in AutoCAD™, where certain details were not accurate later turned out to be, because they did not have the most recent data, or due to data transfer problems between CATIA™ and AutoCAD™. This led to discussions with Hunt trying to resolve the discrepancy noted by Donley with other subcontractors and ultimately with Gehry. Throughout the Peter B. Lewis Building project Donley reflected that the nature of communication between those in their firm and with the general contractor was different from that in their previous jobs:

> I don't think Donley's ever put a project engineer on site with 3D AutoCAD and every column that they pour, they need to plot, you know, in a computer and then slice it at different elevation and then talk back and forth with the engineers, you know, almost once or twice an hour depending on where they were on the job and get them information. You're constantly radioing information back and forth.

Interpretation

Making sense of the Donley activity is less straightforward. The object worlds in the start were different, as in the GQ example, as were the mindsets about knowledge creation. Although Donley were, in effect, engaged in a joint knowledge creating activity, they did not interpret their involvement in this way. They attempted to treat this project like any other, as a knowledge coordination effort, despite the dramatic increase in the complexity.

For example, Donley were not able to easily take advantage of information pooling with Hunt and Gehry. Rather, they relied on a cumbersome routine to translate the designs to a format they were used to using in their practices. Even in this case, however, new practices evolved from having a dedicated AutoCAD™ person on location. While they changed their practices within their organization, they indicated that between organizations, physical interaction was not as frequent as the other firms had engaged in.

Another interesting point is that Donley seem to have spent far less time engaging with the architect, or at least at the architect's office. In the interview a manager at Donley mentioned that, 'Most of the communication went through Hunt. We wouldn't hardly ever call the architect and get information. I mean, it had to go through Hunt so they knew what was going on'. This last point appears to be somewhat confounding, as information pooling did not take place beyond sending translated documents back and forth, and there was no significant collocated human interaction. We found this particularly noteworthy given Gehry's notable emphasis on involving contractors and subcontractors in the design assist process, and their emphasis on collaborative and open interaction as noted by many of the other firms involved in the project.

Discussion

We find that the degree of object world congruence among cross-functional designers influenced the governance structures in an inter-organizational knowledge creating project. Figure 6 illustrates how we locate the episodes in our initial framework.

In the case of GQ (incongruent object worlds) we found a great deal of physical interaction with limited, strategic information pooling. For Zahner (congruent object worlds) the physical interaction was limited while there was a great deal of information pooling. In both of these examples, requisite knowledge was created in order to design and build the complex geometry. In contrast it appeared as though Donley (incongruent object worlds) was resisting or unaware of benefits of the collaboration that Gehry Partners was promoting.

By focusing on the context of each case we see that a highly congruent object world—as evidenced by extensive use of CATIA in Zahner's design practice—seems to lead to decreased physical interaction as well as to an increased level of information pooling. Thus, one might surmise that congruent object worlds, where the ICT artefact is embedded in the practice of designers, may be important for the realization of the 'promise'[3] of ICTs with respect to knowledge creating activity. Our case study illustrates that object world congruence is not immediate. The Zahner example illustrates a situation where classic relational knowledge creating governance—with a great deal of physical interaction and information pooling—has evolved over time and across projects to the transactional-relational quadrant, that realizes the 'promise' of ICT (see Figure 7, arrow #1).

In the GQ example, while the object worlds of at least one designer converged with Gehry's throughout the project, the ICT artefact was not embedded in GQ's practices, thus necessitating joint sense making activity within the firm as well as across firms. Consistent with prior theory of innovative collaboration (Ring and Van de Ven, 1994; Van de Ven *et al.*, 1999) in the GQ case we noted that parties engage in limited, strategic information pooling and a great deal of physical interaction. In addition, over the course of the project, as experience with the system and associated practices improve, the information pooling increases and the

Physical interaction (Action)

Information sharing (Explicit)	Limited	Frequent
Pooled	**Zahner** Congruent object worlds Transactional-relational	Relational knowledge creation
Strategic	**Donley** Arm's length	**GQ** Incongruent object worlds Early stage collaborative Relational

Figure 6 Locating the cases in the framework

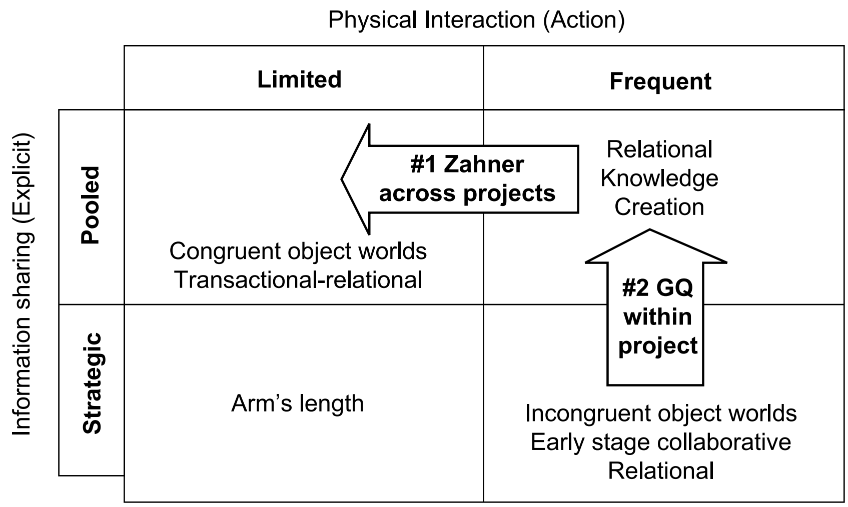

Figure 7 Locating the cases in the framework over time

physical interaction increases significantly. Thus, early stage collaborative activity can evolve into the classic case of relational knowledge creating activity with a high degree of physical interaction as well as information pooling, over the course of a single project (see Figure 7, arrow #2).

These two examples suggest that relational governance practices and object world congruence are dynamic and can change across projects and throughout the project. In contrast, Donley appeared to maintain its incongruent object world, yet, knowledge creating activity did take place, especially within the firm between different groups such as the formwork engineers and the field carpenters—and appeared to be later enabled by intense physical interactions. This leads us to question the 'necessity' of relational inter-organizational forms for knowledge creation as some knowledge creation did occur through arm's length governance practices. However, ultimately their practices were riddled with problems, complications and inefficiencies, which were resolved through greater physical interaction over time. Therefore, we conclude that congruent object worlds, physical interaction and information pooling may not necessarily be required for inter-organizational knowledge creation, but rather facilitate such activity.

Implications for research and practice

Our analysis poses a number of implications for research in three broad discourses: (1) information systems; (2) inter-organizational governance; and (3) construction management. First, by recognizing the importance of an object world for the knowledge creating activities of a designer, we emphasize practices associated with a given ICT as well as specific attributes of the technology. For example, while both Donley and Gehry used a specific form of information technology known as '3D CAD', just as both GQ and Zahner used the CATIA brand of 3D CAD, each organization embedded the information technology artefact into the practices of their designers in different ways. Therefore, this critical aspect of their object worlds could be more or less congruent. While our data do little to establish causal inference from object world congruence to variance in expected outcomes, if the outcomes are assumed to be relatively consistent (i.e. a high degree of knowledge creation) we find that tracking object world congruence does provide a powerful theoretical lens for understanding what forms of relational governance structures can be potentially realized at a given stage of collaboration. Also, as the technology is a critical enabler of a designer's design activity, much of the knowing-in-practice necessary to collaborate effectively appears to be embedded in the designer's interactions with the technology. When the technology is not yet embedded in the practices of all designers, a greater amount of physical interaction is necessary to collaborate effectively. Once the technology becomes embedded, however, the requisite knowing-in-practice is established as an infrastructure upon which more explicit forms of knowledge transfer—in the form of information pooling—can be created as the dominant form of activity.

This research informs the literature on inter-organizational information systems, particularly with respect to innovative collaboration (Bensaou, 1997; Choudhury, 1997), by unpacking the role of the ICT in inter-organizational knowledge creation. It is not simply a matter of seeing the software used across cases, but the ICT should also be embedded in the object worlds of the designers to realize the 'promise' of ICT. Further, we extend the recent work that describes the codification resulting from taking the physical element, or 'embodiment', out of an interaction as necessarily objectifying, or eviscerating that interaction (Levina and Vaast, 2006; Vaast and Levina, 2006). Instead, we see that when the ICT is embedded in the object worlds of the designers, and those object worlds become congruent over time, the inevitable outcome need not result in a settled, rationalized process or inevitable conflict. But rather, it can enable innovation and knowledge creation across groups.

Our analysis of object world congruence and relational activities associated with inter-organizational knowledge creation suggests a dynamic model of knowledge coordination and creation associated with relational, knowledge creating inter-organizational forms (Figure 7). When firms wish to engage in relations that are 'thicker' than arm's length, the first step may be to strategically share information (Van de Ven *et al.*, 1999), or to pool a greater deal of information and monitor the actions of partnering firms (Helper *et al.*, 2000). Either way, our analysis indicates that a fundamental step to advance relationships and enable them to be more productive is to promote object world congruence. A key step associated with this activity is to embed the common ICT into the core design practices of involved parties. This establishes some form of common practice and 'know-how' when it comes to design knowledge that different functional groups can bring to design. When object worlds are more congruent, information technology embedded in design practice can fulfil its promise of increased information pooling while simultaneously reducing the need for physical interaction. A logical extension of this model is that once multiple object worlds become congruent across multiple organizations, joint knowledge creating activity can again oscillate towards arm's length transactions like in the case of Argyres' (1999) study (thus coming full circle).

In relation to the literature on construction management, as well as the broader organizational literature, this work calls for serious consideration of the materiality of ICT artefacts and their significance (Leonardi and Barley, 2008). While there has been an increasing focus on the social processes that are important to project networks in construction (e.g. Bresnen *et al.*, 2003), there is limited attention to the way these social processes are intertwined with ICT artefacts, particularly in contexts of innovative designs. This study not only calls attention to the importance of various ICT artefacts, but proposes a unique process model about the interaction of particular ICTs and the relevant social and inter-organizational governance arrangements, thus extending some of the work that addresses the role of information technology artefacts in innovative practices (e.g. Boland *et al.*, 2007; Whyte *et al.*, 2008) and links these observations to inter-organizational governance. Further, it extends the work on project forms beyond the capturing of knowledge (Brady and Davies, 2004; Bresnen *et al.*, 2004) to fostering the knowledge creation within the project.

The practical implications of this research are threefold. First, in the case of technologically mediated knowledge creation, such as joint innovative design, managers must carefully consider integrating the communication medium and tools of a project into actual design activities—thus truly creating an interpenetrating process. Leveraging a technological tool to manage collaboration information separately from the practices where design actually occurs will actually result in increased physical interaction and potential

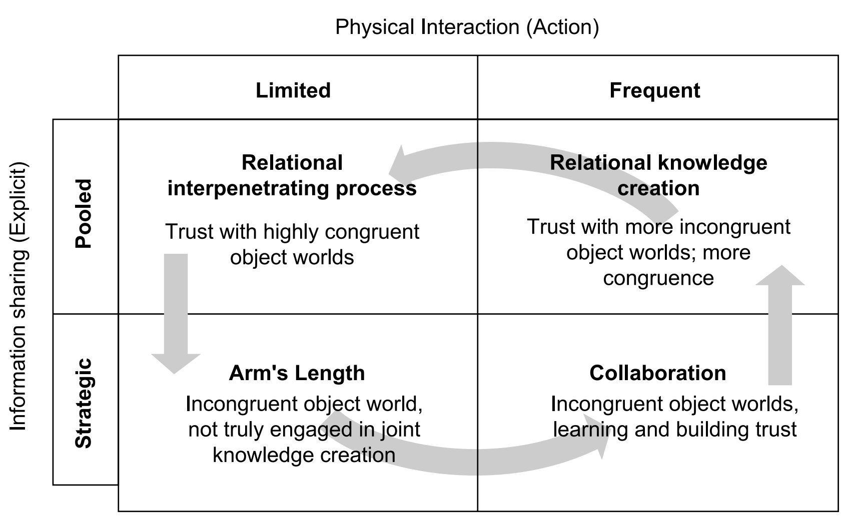

Figure 8 A learning model of relational inter-organizational governance

redundancies and expenses. A second implication is that managers should be cognizant of the way in which designers approach their design task before forming a multidisciplinary team. In cases where these practices are highly congruent, communication may not be a serious issue. However, in situations where the approaches are significantly different, there will likely be a transitional change phase where congruence needs to be established. Finally, practitioners can use our framework as a guide in understanding inter-organizational relationships and technology's role in coordinating these relationships. This insight may be relevant to analysis of inter-organizational infrastructures referred to as 'building information modelling' (BIM) in the construction industry. As the adoption of such environments becomes more prevalent, the dynamic learning view of inter-organizational governance and object world congruence may help set expectations realistically. Certain types of organizing are better for certain types of applications, and the dynamic framework presented above offers managers a point of reflection that can guide how they need to manage their inter-organizational relationships. As our data reveal, one can engage in joint knowledge creation in each of the quadrants, but there are different ramifications and implications for each form.

Limitations and future research

This research was geared towards inductive theory building based on one case. While our findings are rooted in rigorous analysis of qualitative data, these findings are borne of our interpretations of those data over the course of a multi-year effort. We have not exhausted other possible interpretations, nor explored all possible confounding factors. Further our operationalization of the notion of object world congruence is still notably thin—essentially using CATIA as a proxy for adequate object world congruence. While this is certainly defensible if one wishes to limit the focus on issues of congruence, in order to get a more thorough understanding of object worlds one would need to explore the entire ecology of artefacts embedded in the activities of designers (cf. Bailey *et al.*, 2007). Further, we describe little about the motivation and processes behind embedding the artefacts in project team practices. CAD artefacts are not adopted and implemented across a construction project network without problems and only with intended outcomes, and can have a variety of material effects (Harty, 2008). In this paper we attend neither to the drivers nor to the process of the ICT design or implementation. Such issues might call to attention some of the unique features of the Gehry case—since he is a celebrity of sorts and many firms have a number of additional pressures to comply with Gehry that would not generalize well across other contexts. We view these limitations as opportunities to explore both progressively finer details and other patterns in other contexts.

Conclusion

We used a Gehry Partners' construction project and associated inter-organizational practices to gain insight into the role of ICTs in joint knowledge creation. We conclude that groups with congruent object worlds that involve a joint ICT artefact embedded in their practices will likely require less frequent physical interaction during the knowledge creation process and will engage in larger amounts of information pooling. For groups with incongruent object worlds our data indicate that physical interactions will be more heavily required, while information pooling may be limited. In areas where object worlds are congruent, yet the communication technology is not embedded in design practice, we would expect to see a great deal of both physical interaction and information pooling. Our data also suggest a dynamic theory of inter-organizational learning, where knowing-in-practice becomes embedded into specific ICT-related design practices. At first such knowing-in-practice must be shared through physical interaction. Later, this knowing-in-practice is embedded in the object worlds of the designers and physical interactions can be reduced while knowledge can still be jointly created. Accordingly, our study reinforces and provides a framework to view joint knowledge creation from social-interpersonal, technical and inter-firm governance levels.

The study of 'design' is important to the management of inter-organizational innovation because joint knowledge creation necessarily involves design. This is clear in cases such as Gehry's radical architecture, or in cutting-edge aerospace projects like stealth bombers (Argyres, 1999) or rockets (Majchrzak *et al.*, 2000). However, it can also apply to other contexts across functional disciplines. For example, effective, knowledge creating management practices have been likened to 'designing' (Boland and Collopy, 2004). Given the continued demand for innovation and flexibility which frequently depend upon collaboration and information technology, we believe our work can open new vistas in fostering joint knowledge creation among firms.

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Notes

1. See for example: Airbus's design troubles with CATIA™ v4 and v5 (Prawel, 2008).
2. Up to the point of the analysis conducted for this study we drew on over 100 interviews in over 20 firms involved with Gehry Partners' projects. These cover the following finished or ongoing Gehry projects: Guggenheim Museum in Bilbao, Spain, the Experience Music Project (EMP) in Seattle, the Millennium Bandshell in Chicago, the Bard College Center for the Performing Arts, the MIT Stata Center, and the Princeton Science Library. During the period of data analysis our research group consisting at the time of three professors and four PhD students engaged in weekly meetings to compare and analyse the data. These meetings took place over the course of 2002 to 2007.
3. The 'promise' of ICTs refers to expectations in line with the contention of Malone and associates (1987) that complex and highly interactive activities such as joint knowledge creation might behave more like arm's length market transactions with the help of ICT.

References

Argyres, N.S. (1999) The impact of information technology on coordination: evidence from the B-2 'stealth' bomber. *Organization Science,* **10**(2), 162–80.

Bailey, D.E., Leonardi, P.M. and Chong, J. (2007) Conceptualizing and understanding technology interdependence in knowledge work. Paper presented at the Academy of Management Annual Meeting, Philadelphia, PA, 2–3 August.

Bas, E. (2001) Frank Gehry design is striking, unusual, *Snips Magazine,* 1 October, available at http://www.snipsmag.com/Articles/Feature_Article/eac74db667aa7010Vgn VCM100000f932a8c0

Baxter, R. (2008) Middle range theorizing about information technology impact: a study of 3D CAD impact on construction work practices, PhD dissertation, Information Systems Department, Case Western Reserve University, Cleveland, OH.

Bensaou, M. (1997) Interorganizational cooperation: the role of information technology: an empirical comparison of US and Japanese supplier relations. *Information Systems Research,* **8**(2), 107–24.

Berente, N., Srinivasan, N., Yoo, Y., Boland, R.J. and Lyytinen, K. (2007) Binate diversity and the rolling edge of design networks. Paper presented at the International Conference on Information Systems, Montreal, Canada, 9–12 December.

Boland, R.J. and Collopy, F. (2004) *Managing as Designing,* Stanford University Press, Stanford, CA.

Boland, R.J. and Tenkasi, R.V. (1995) Perspective making and perspective-taking in communities of knowing. *Organization Science,* **6**(4), 350–72.

Boland, R.J., Lyytinen, K. and Yoo, Y. (2007) Wakes of innovation in project networks: the case of digital 3-D representations in architecture, engineering, and construction. *Organization Science,* **18**(4), 631–47.

Brady, T. and Davies, A. (2004) Building project capabilities: from exploratory to exploitative learning. *Organization Studies,* **25**(9), 1601–21.

Bresnen, M. and Marshall, N. (2000) Partnering in construction: a critical review of issues, problems and dilemmas. *Construction Management and Economics,* **18**, 229–37.

Bresnen, M., Edelman, L., Newell, S., Scarbrough, H. and Swan, J. (2003) Social practices and the management of knowledge in project networks. *International Journal of Project Management,* **21**, 157–66.

Bresnen, M., Goussevskaia, A. and Swan, J. (2004) Embedding new management knowledge in project-based organizations. *Organization Studies,* **25**(9), 1535–55.

Brown, J.S. and Duguid, P. (1991) Organizational learning and communities-of-practice: toward a unified view of working, learning, and innovation. *Organization Science,* **2**(1), 40–57.

Bucciarelli, L.L. (1994) *Designing Engineers,* MIT Press, Cambridge, MA.

Choudhury, V. (1997) Strategic choices in the development of interorganizational information systems. *Information Systems Research,* **8**(1), 1–24.

Coase, R.H. (1937) The nature of the firm. *Economica,* **4**(16), 386–405.

Cook, S.D.N. and Brown, J.S. (1999) Bridging epistemologies: the generative dance between organizational knowledge and organizational knowing. *Organization Science,* **10**(4), 381–400.

Dyer, J.H. and Singh, H. (1998) The relational view: cooperative strategy and sources of interorganizational competitive advantage. *Academy of Management Review,* **23**(4), 660–79.

Gal, U., Lyytinen, K. and Yoo, Y. (2008) The dynamics of IT boundary objects, information infrastructures, and organisational identities: the introduction of 3D modelling technologies into the architecture, engineering, and construction industry. *European Journal of Information Systems,* **17**(3), 290–304.

Gann, D.M. and Salter, A.J. (2000) Innovation in project-based, service-enhanced firms: the construction of complex products and systems. *Research Policy,* **29**(7), 955–72.

Granovetter, M. (1985) Economic action and social structure: the problem of embeddedness. *American Journal of Sociology,* **91**(3), 481–510.

Grover, V., Teng, J.T.C. and Fiedler, K.D. (2002) Investigating the role of information technology in building buyer–supplier relationships. *Journal for the Association of Information Systems,* **3**, 217–45.

Harty, C. (2005) Innovating in construction: a sociology of technology approach. *Building Research & Information,* **33**(6), 512–22.

Harty, C. (2008) Implementing innovation in construction: contexts, relative boundedness and actor-network theory. *Construction Management and Economics,* **26**(10), 1029–41.

Helper, S. and Khambete, S. (2005) Off-shoring, interfaces, and collaboration across the supply chain: a case study in automotive product development. Working paper prepared for the International Motor Vehicle Program, Case Western Reserve University, Cleveland, OH.

Helper, S., MacDuffie, J.P. and Sabel, C. (2000) Pragmatic collaborations: advancing knowledge while controlling opportunism. *Industrial and Corporate Change,* **9**(3), 443–88.

Inkpen, A.C. and Dinur, A. (1998) Knowledge management processes and international joint ventures. *Organization Science,* **9**(4), 454–68.

Katzy, B., Evaristo, R. and Zigurs, I. (2000) Knowledge management in virtual projects: a research agenda, in *Proceedings of the Thirty-Third Hawaii International Conference on System Sciences,* Maui, Hawaii, 4–7 January.

Lawrence, P.R. and Lorsch, J.W. (1967) *Organization and Environment: Managing Differentiation and Integration,* Harvard University Press, Cambridge, MA.

Leonardi, P.M. and Barley, S.R. (2008) Materiality and change: challenges to building better theory about technology and organizing. *Information & Organization,* **18**, 159–76.

Levina, N. and Vaast, E. (2006) Turning a community into a market: a practice perspective on information technology use in boundary spanning. *Journal of Management Information Systems,* **22**(4), 13–37.

Majchrzak, A., Rice, R.E., Malhotra, A., King, N. and Ba, S. (2000) Technology adaptation: the case of a computer-supported interorganizational virtual team. *MIS Quarterly,* **24**(4), 569–600.

Malhotra, A., Gosain, S. and El Sawy, O. (2005) Absorptive capacity configurations in supply chains: gearing for partner-enabled market knowledge creation. *MIS Quarterly,* **29**(1), 145–87.

Malone, T.W., Yates, J. and Benjamin, R.I. (1987) Electronic markets and electronic hierarchies. *Communications of the ACM,* **30**(6), 484–97.

Nonaka, I. (1994) A dynamic theory of organizational knowledge creation. *Organization Science,* **5**(1), 14–37.

Powell, W.W. (1990) Neither market nor hierarchy: network forms of organization. *Research in Organizational Behavior,* **12**, 295–336.

Powell, W.W., Koput, K.W. and Smith-Doerr, L. (1996) Interorganizational collaboration and the locus of innovation: networks of learning in biotechnology. *Administrative Science Quarterly,* **41**(1), 116–45.

Prawel, D. (2008) Interoperability isn't (yet) and what's being done about it, in Bartolo *et al.* (eds) *Virtual and Rapid Manufacturing,* Taylor and Francis Group, London, UK.

Ring, P.S. and Van de Ven, A.H. (1994) Developmental processes of cooperative interorganizational relationships. *Academy of Management Review,* **19**(1), 90–118.

Sabel, C. (2004) Neither modularity nor relational contracting: inter-firm collaboration in the new economy. *Enterprise and Society,* **5**(3), 388–403.

Sapsed, J. and Salter, A. (2004) Postcards from the edge: local communities, global programs and boundary objects. *Organization Studies,* **25**(9), 1515–34.

Scarborough, H., Swan, J., Laurent, S., Bresnen, M., Edelman, L. and Newell, S., (2004) Project-based learning and the role of learning boundaries. *Organization Studies,* **25**(9), 1579–600.

Schultze, U. and Orlikowski, W. (2004) A practice perspective on technology-mediated network relations: the use of internet-based self-serve technologies. *Information Systems Research,* **15**(1), 87–106.

Sydow, J., Lindkvist, L. and DeFillippi, R. (2004) Project-based organizations, embeddedness and repositories of knowledge: editorial. *Organization Studies,* **25**(9), 1475–89.

Taylor, J.E. and Levitt, R. (2007) Innovation alignment and project network dynamics: an integrative model for change. *Project Management Journal,* **38**(3), 22–35.

Uzzi, B. (1997) Social structure and competition in interfirm networks: the paradox of embeddedness. *Administrative Science Quarterly,* **42**(1), 35–67.

Vaast, E. and Levina, N. (2006) Multiple faces of codification: organizational redesign in an IT organization. *Organization Science,* **17**(2), 190–201.

Van de Ven, A.H., Polley, D.E., Garud, R. and Venkataraman, S. (1999) *The Innovation Journey,* Oxford University Press, New York.

Whyte, J., Ewenstein, B., Hales, M. and Tidd, J. (2008) Visualizing knowledge in project-based work. *Long Range Planning,* **41**, 74–92.

Williamson, O.E. (1985) *The Economic Institutions of Capitalism,* The Free Press, New York.

Winch, G. (1998) Zephyrs of creative destruction: understanding the management of innovation in construction. *Building Research & Information,* **26**(4), 268–79.

Yin, R.K. (2003) *Case Study Research: Design and Methods,* Sage, Thousand Oaks, CA.

Yoo, Y., Boland, R.J. and Lyytinen, K. (2006) From organization design to organization designing. *Organization Science,* **17**, 215–29.