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Information Technology Impact on Work Practices: A Study of 3D CAD Capabilities in Architecture, Engineering, and Construction

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Abstract

The current set of concerns for research on the impacts of information technology (IT) on organizational work is unduly restricted. The intent behind the use of new IT is to alter work practices of an organization, but how this happens and in what form has received limited attention; in particular, how specific types of use relate to specific impacts. Theoretical explanations have moved us already beyond simplistic determinism where IT impact is direct without due analysis of the context and the use. Such explanations include socio-technical theory, social construction of technology, structuration theory, and social representations. These studies have expanded considerably our understanding how IT use will lead to changes in work practices and thereby to organizational transformation. The way in which IT impact is currently conceptualized falls short in the current business environment where IT use is embedded, pervasive and diverse. Based on calls to theorize rigorously about the IT artifact we explore in more detail how specific IT capabilities and how they impact work practices. To this end we suggest several analytical dimensions to analyze work practices to understand in more detail how changes in IT use and work practices interact in dynamic, interorganizational settings. We illustrate the breadth and diversity of potential IT impact by illustrating how the use of novel capabilities associated with 3D technologies in the Architecture, Engineering, and Construction (AEC) industry impacted multiple dimensions of work practice and ultimately played a significant role in changing work practices of builders, architects and engineers. We conclude by identifying implications to research and potential future research directions.

Keywords: Information Technology Impact, 3D CAD, Work Practice, Work Practice Change, AEC, Design

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Introduction

Studying the impact of IT on individuals, organizations, and society has been a theme since the inception of the information systems field (Leavitt and Whisler 1958). Without the underlying assumption of the impact of IT there would be less interest in understanding how to control or moderate the consequences of IT through design, development, implementation, or management. However, understanding how and why IT impacts take place can be challenging. In their seminal review of IT impacts Attewell & Rule (1984) state, "…we suspect that the transformations in the organizational life through computing are so multifarious as to encompass the most disparate cause-effect relations in different contexts" (p. 1190). As firms continue to increase their reliance upon IT, researchers face the challenge of capturing the disparate, indirect, and latent effects of IT.

We find that a solution to this problem aligns well with the recent call by scholars to theorize more about the IT artifact (Orlikowski and Iacono 2001). Orlikowski and Iacono give several recommendations about how to open the IT black box:

> The need to "shift… towards explicit theorizing about specific technologies with distinctive cultural and computational capabilities, existing in various social, historical, and institutional contexts, understood in particular ways, and used for certain activities". (Orlikowski 2000, p. 131, emphasis added)
>
> It "requires that the detailed practices of their use [of IT] be recognized and integrated into extant theories. Thus, *how people engage* with various technological artifacts in the course of working, learning, communicating, shopping, or entertaining themselves must become a central theoretical concern. (ibid, p.132)

We also find that in addition to understanding better the IT artifact there must also be a careful analysis of what the IT artifact is supposedly impacting. This insight was made by Mason (1984) over twenty years ago:

> The field needs a theory of technology and a *classification scheme* that will permit (1) similar groupings of hardware, software, data, rules, procedures, and people to cluster together (for example, personal computers are different from large mainframes, local networks are different from worldwide networks and stand alones, and integrated data bases are different from collections of independent files); and (2) different groupings to be clearly distinguishable from one another. … In addition to needing a better understanding of *the thing doing the impacting*, we must also be clearer about *the thing that is impacted*. (Mason, 1984, p. 183, emphasis added)

Mason's insights of the need to develop more nuanced accounts about both IT and what IT impacts is equally valid today. While Orlikowski & Iacono's emphasis seems to be more focused on achieving greater theoretical accuracy about the role of IT, Mason (1984) was clearly aiming to advance accuracy in a way that generalizability[1] might be improved (e.g., through the use of classification schemes). Blending both of these insights into a balanced approach suggests a possible iteration between opening the IT black box to improve accuracy as well as closing it to improve the generalizability. As Mason stated, we need to be more specific about what IT impacts. In this work we focus on the impact of IT on work practices. We choose work practices for several reasons. First, the two major theoretical streams that have been applied in the study IT

[1] See Weick's (1979) discussion on the trade offs between generalizability, accuracy, and simplicity in theory building.

impacts are contingency (e.g., Sambamurthy and Zmud 1999) and structuration theories (Giddens 1984). Although in different ways, both highlight the importance of work practices as playing a significant role in organizational change and outcomes[2]. Second, IT is often appropriated at the individual level and work practices are instantiated at an individual level. Only recently have researchers begun to study the IT and work practice relationships (Vaast and Walsham 2005). Theoretical explanations for how IT impacts organizations, groups, and individuals have steadily improved. We seek to improve these accounts by developing an understanding of how particular IT capabilities impact work practices. Focusing on IT capabilities vs. IT adoption, use, investment or spending helps to open the IT artifact black box.

We extend the research on IT impacts to work practices by developing analytical dimensions of work practices and their relationships to IT capabilities from case study research in Architecture, Engineering, and Construction (AEC). The AEC industry is composed of differentiated professionals that rely on IT for the coordination of different expertise from the conceptual development of an idea to the physical construction of a building. Hence, our observations ranged across the cognitive, representational, relational, and material aspects of work practice in each of the professions. We observed that IT impact occurs within, across, and between these professional groups.

The paper is organized as follows. We first review literature on IT impacts and discuss IT capabilities and analytic dimensions of work practices. Next we present methods of data collection and analysis. We then n four will review three examples of IT impact from the AEC case studies and follow with a discussion. The paper concludes by observing some ramifications of our study for future IT impact studies. It also suggests future lines of research.

Literature Review

Perspectives of IT Impact Research

The study of IT impacts continues to be regarded as one of the core elements of IS research.

> The set of core properties of the IS discipline includes… as a consequence of use, the impacts (*direct and indirect, intended and unintended*) of these artifacts on the humans who *directly (and indirectly*) interact with them, structures and contexts within which they are embedded, and associated collectives (groups, work units, organizations). (Benbasat & Zmud 2003, p. 186, emphasis added)

The expectation of IT impact underlies the work of research and practice dealing with IT. Although the understanding of the relationships between IT use and organizational outcomes has improved we still lack approaches to considering the impact of IT on more individual level variables, such as work practices. A better understanding in this area could lead to improved approaches of IT implementations as well as to strategies that would make better use of IT.

IT impacts are typically discussed in a general way. There is recognition of direct/indirect and intentional/unintentional impacts, and that IT impacts can be first or second order changes from the initial adoption or use of IT (Rogers 1984). Several theoretical bases have been adopted in IT impacts research. From the literature we focus on three distinct theoretical accounts that have been employed.

[2] This explanation is taken up in the literature review.

Deterministic. Early conceptions beginning with Leavitt and Whisler's (1958) predictions about changes to middle management cast a deterministic light on the subject of IT impacts. When adopted, IT was thought to cause certain changes in organizations, such as centralization of decision making or decentralization. While there were relatively few studies that took up these claims, those that did resulted in contradictory and unexpected outcomes regarding the impact of IT (Robey 1981). In the 1980s scholars drew upon the previous contradictory and unsystematic studies as an impetus to forge new ground theoretically on the understanding of IT impacts (Kling 1980; Robey 1981; Hirschheim 1986). A common conclusion to such reviews is the need to approach these problems from a multiplicity of views (Attewell and Rule 1984; Ang and Pavri 1994).

Contingency. Early socio-technical models (Leavitt 1965) were helpful to move away from simplistic cause and effect outcomes of the impact of IT by identifying other contextual factors. Analyses of contextual variables, such as environmental uncertainty, technology, size, management objectives, or political strategies, (Robey 1981) led to primarily contingency type models of explaining IT impacts. Research on the IT productivity paradox (e.g., Brynjolfsson 1993) is an example of research that began with deterministic expectations of IT impacts (e.g., the effect of IT spending on national, industrial, or firm level performance) and adopted more contingency-based explanations. For example, the link from IT to firm performance is contingent upon IT capabilities, work practices, or complimentary investments (Brynjolfsson and Hitt 1998; Bharadwaj 2000).

Structurational. The third perspective of IT impacts is primarily rooted in structuration theory (Giddens 1984). Structuration theory emphasizes the reciprocal relationship between individual level agency and higher level social structures (Giddens 1984). For IS research (Orlikowski 1992; DeSanctis and Poole 1994; Orlikowski 1996) structuration provides an explanation for linking individual action (e.g., adoption and use of IT) with enabling organizational structures (e.g., decision to implement IT) as well as organizational outcomes (e.g., increased centralization or decentralization). Determinism is averted because structures (e.g., IT) are both the outcome and the medium of human action (e.g., the choice to adopt and use) (Giddens 1984). Structuration theory also enables a broader understanding of the interactions at multiple levels of analysis: individual, organizational, and societal.

Opening the IT Black Box: IT Capabilities

Both contingent and structurational views have strengths and weaknesses. Contingency based views have proven successful in adding greater clarity to the IT productivity paradox at the firm level (e.g., Brynjolfsson 1993; Brynjolfsson and Hitt 1998; Bharadwaj 2000). However, others would argue that contingency models are still deterministic in that they ignore the role of human agency into their theoretical account (Orlikowski 1992). Structuration theory states that human choice is constrained and enabled by social structures, and human choice in turn reproduces or changes these social structures (Giddens 1984). From a theory building perspective, structurational theories tend focus more on theoretical accuracy at the expense of simplicity and generalizability (Weick 1979).

In terms of conceptualizing the IT artifact, both contingency and structurational approaches have tended to black box IT. For example, contingency views may take the proxy view of technology by focusing on IT spending and investment. Although structurational approaches employed in IS research which tend to take an ensemble view of technology have also been criticized for not being more accurate in their theorizing about the IT artifact. Orlikowski and Iacono (2001) state, "Even the ensemble views of technology, which do engage with the social and embedded aspects of technology development and use, tend not to take into account the multi-generational and emergent aspects of technological artifacts that arise as designers, developers, users, regulators, and other stakeholders engage with evolving artifacts over time and across a variety of contexts"(Orlikowski and Iacono 2001, p. 132). There is a tendency to focus on *IT use* and not articulate more carefully the IT capabilities. Black boxing the IT artifact into IT use is helpful to highlight the social and contextual aspects of IT impacts, but does not provide any nuanced theoretical understanding of the how and why certain types of IT may or may not lead to different outcomes. Correctly highlighting that IT use is not the same as the IT artifact (i.e., software and hardware, Kling 1980; Orlikowski 2000) brings to light that the work practice is a significant unit of analysis in understanding IT use (Orlikowski 2002). We do not deny that theoretically the appropriation (or lack thereof) of IT is the mechanism by which reproduction and change of work practices takes place. Moreover, we understand that IT capabilities[3] are not deterministic inputs to change, but it is through the IT appropriation into a materially and socially situated context (Suchman 1987) that changes to work practice occur. However, some limits of the usefulness of this approach stem from its vagueness in articulating the nature of the IT artifact and its relationship to distinctive attributes of work practices. Consequently, the underlying theoretical details of what happens between IT use and organizational outcomes remains clouded. What we have is a high level theoretical account that is inadequate as we attempt to articulate the impact of IT as it cascades over time and across contexts. It is within these lower layers that the research literature is theoretically vague about how to answer questions such as: Why are certain IT capabilities adopted into certain work practices while others are not? How do IT appropriations that lead (or do not lead) to (in)direct changes to work practices continue to cascade across time and space to other work practices or entities? We doubt that there is an all encompassing theoretical language by which we could frame all the ways in which the IT and work practice relationships are organized as they cascade over time and contexts. However, because IT capabilities and work practices are reciprocally related (Orlikowski 2002; Vaast & Walsham 2005), discussions of opening the IT artifact should be accompanied by opening the details of work practices to avoid a regress to a deterministic account of the impact (or lack thereof) of IT capabilities.

One approach to overcoming this difficulty is to focus on IT capabilities along with IT use. IT capabilities are those designed in or latent capacities that result through appropriation. An example of early IT capabilities was to automate and store information. Other IT capabilities include the ability to represent data and information.

Opening the Work Practice Black Boxes: Work Practice Classifications

Another area for improvement is the elaboration of work practices. Both contingency and structurational approaches emphasize, albeit for different reasons, the importance of work practices. For contingency-based views work practices are processes that take place in the organization. They are considered complementarities in that they may enable firms to capture

[3] The shift to "IT capabilities" instead of retaining "IT use" is purposeful. By capabilities we mean capacity of the IT artifact (i.e., software and hardware) to perform a certain function (e.g., compute). We stick to the notion that IT use is the mechanism to explore the impact of IT capabilities on work practices. However, we emphasize IT capabilities when exploring the interaction between IT and work practice change.

greater productivity returns from their IT investments (Brynjolfsson and Hitt 1998). There is no discussion of ontological components of work practices from this view as they are merely a contingent factor. For the structurational perspective work practices take a more central role theoretically in that they represent instantiations of individual level agency which are both constrained and enabled by structures (e.g., information technology, organizational policies, etc…). Work practices can be defined as possessing three ontological components: they are 1) recurrent, 2) materially and socially situated, and 3) involve active engagement by members of a community (Orlikowski 2002, p. 256).

> Practices are engaged in by individuals as part of the ongoing structuring processes through which institutions and organizations are produced and reproduced. They are thus both individual (because performed by actors in their everyday action) and institutional (because they shape and are shaped by organizational norms and structures). (Orlikowski 2002, p. 256)

The above quote highlights the challenge that in order to understand work practices one must take into account multiple levels of analysis. Researchers that have adopted the structuration perspective often implement the practice-oriented approach to observing the research setting (Orlikowski 2000; Schultze 2000). The practice-oriented approach focuses on what people do and how they do it. Thus, detailed accounts of work practices are possible. For example, based on detailed observations of practices, Orlikowski (2002) develops classifications of practices that lead to successful distributed software development. Another example of grouping work practices is Schultze's (2000) account of informing practices of three groups of knowledge workers.

To build on these approaches we develop four analytical dimensions of work practices by drawing upon observations in the introduction of new 3D technologies into the AEC industry. Our observations led us to develop classifications of work practices as we trace the appropriations of IT capabilities across AEC projects. The classifications point to possible generalizations of the IT capability and work practice relationships to be tested more rigorously in AEC as well as other contexts.

IT Capabilities and Work Practice Relationship

> "Medium, thought, artifacts, and work processes are deeply intertwined in ways we do not fully understand." (Ruhleder 1994, p. 210)

A few streams of literature have captured the micro level issues of how work practices change with IT use (Vaast & Walsham 2005). Vaast and Walsham theorize that the change or reproduction of work practice occurs as individuals make sense of their actions (i.e., the social representations (Moscovici 1984) of their actions). As individuals experience dissonance (Festinger 1957) between their IT usage (i.e., their actions), work practices, and social representations, they will strive for consonance through a mutual, reciprocal change of IT usage, practices, or social representations. In the case of their work, they observed a gradual change in which sales persons using the IT system adopted new work practices, and felt that these were socially acceptable in their profession. Changes occurred to work practices occurred when sales persons reframed their IT usage as helpful in light of the social representation of their profession.

Work stemming from the sociology of scientific knowledge has also documented interactions between various IT artifacts and work practices of groups. For example, actor-network theory emphases that technologies are as important as human actors in understanding how scientific laws and theorize are generated and substantiated (Latour 1987). Technologies, humans, and their practices then become intertwined to form a network of allies that support the creation of scientific knowledge. Other related work in the sociology of scientific knowledge utilizing the concept of boundary objects (Star and Griesemer 1989) has focused more on how different groups are able to coordinate their activities while maintaining separate interests and identity. These theoretical bases are growing in organizational research (e.g., Henderson 1991; Carlile 2002; Sapsed and Salter 2004), however, they have not yet begun to generalize the relationships between IT artifacts and work practices.

Analytical Dimensions of Work Practices

Based on our observations within the AEC industry we developed four interrelated, analytical groups of work practice related to IT capabilities: cognitive, representational, relational, and material. For example, we saw that 3D CAD enabled realistic 3D visualization that directly affected the design practice and consequently how the building was represented. The IT capabilities did not just enable re-representations of the same information, but included distinctive differences when compared to the existing representational practices in AEC of using 2D representations. Furthermore, this new IT capability was employed with the intention of affecting the eventual material work practice of carpenters in the field that would construct the building. In this case, a representational capability was envisioned as flowing through different work practices, across different organizations and communities to affect their different representational capacities and other forms of work practice, ultimately the physical construction of a building. During the project, the use of different representational system was also related to a different 3D perspective of how representations relate to the practice of building. These changes are considered non-trivial by individuals representing multiple professions with vast experience.

In Table 1 we define these classifications of practices:

	AEC Examples
Cognitive practices are ways of thinking manifested through beliefs, perceptions, and general understanding about the work practice engaged in.	What is a building, How to organize, How to work and build, design, etc.
Representational practices are those work practices that deal with the creation, manipulation, and sharing of design ideas with other social worlds via symbols in order to enable the fulfillment of the design idea.	Development of drawings and specifications
Relational practices are the work practices that are used to engage communication or dialogue among social worlds or individuals.	Regular coordination meetings between GC and subs
Material practices[4] are those work practices that deal with the actual physical manipulation of other physical objects, substances, or artifacts.	Building practices (framing, forming and pouring concrete, etc…)

Table 1. Analytical practice attributes defined

These analytical dimensions are generated inductively from our case data and are not ontological attributes, mutually exclusive, or exhaustive groupings of work practices. For example, representational work practices have the ontological elements of work practice—they

[4] Material work practices are not included in the table as they are defined these are those practices that deal with physical manipulation of other material artifacts. For our work material practices were only indirectly affected by the use of new representational and coordinating capabilities.

are recurrent, situated materially and socially, and take place within a community of practice (Orlikowski 2002). Dimensions may not exist independently of other dimensions. Representational practices do not take place independently of cognition, and they may or may not be related to the relational practices. For an architect a representational practice might be the creation of contract drawings and specifications.

The classifications chosen are broad and they can be traced to prior literature. Relating to cognitive practices, Lave (1988) and Hutchins (1995) identified that cognition is situated action bound by culture, mind, body and context. In terms of representational practices studies have highlighted knowledge representation (Boland and Tenkasi 1995; Carlile 2002), problem representation (e.g., DSS and GDSS studies, see for example Vessey (1994)or Speirer and Morris (2003), and GIS and spatial representations (Tarantilis and Kiranoudis 2002). In terms of relational practices, there are vast number of studies focusing on trust, power, and political dimensions within organizational studies (Pfeffer 1981) and within IS research (Markus 1983). Relating to the material nature of information systems could be traced to earlier studies that emphasized the move from non-material forms of work to knowledge related pursuits, or to studies emphasizing the move from material, paper-based systems to digital systems (e.g., Henderson 1991)

Exploring IT Impact Paths in Architecture, Engineering, and Construction (AEC)

In this section we discuss our methods for collecting and analyzing data. The data for these illustrations is from our ongoing research studying the impact of 3D CAD/CAM technologies to AEC. First, we provide details on the data collection and analysis, a background of the AEC industry, and then we look at three examples which illustrate IT capabilities and work practices.

Background of the AEC Industry

The AEC industry is a project based industry in which different professions routinely collaborate only for the length of the design and construction project. AEC projects require the coordination of many diverse types of professionals, designers, laborers, and others. This distributed environment leads to one of the most significant challenges: the ability to mobilize the knowledge and resources in a predictable and efficient fashion. As an executive from one of the largest construction companies in the U.S. stated to us:

> It is an industry where it's absolutely amazing of the inability of the people to communicate with each other, and actually have multiple parties in the same conversation. And when you talk to them outside of the room you can't believe it was the same conversation. It's just absolutely amazing to me, the ability of people to filter information from their own perspective and use it. And that's one of the major issues for us in the construction industry as we engage more and more people. The simplest construction job engages thousands of people when you add up all of the designers, people in the factories, people in the fields. And they come from the whole breadth of your society.

The AEC Coordination Process. At a high level the goal of the design process is to take client needs and provide a design solution into a construction package that can bid upon and used by a general contractor to construct the building. In a general sense, bid packages consist of 2D drawings that show *where* to build and written specifications that detail *what* to build. A contract between the winning bidder (i.e., general contractor) and the owner details the expectations of both parties throughout the construction to the completion of the project. The primary role of the general contractor is to coordinate the work of all of the sub-contractors and field workers. In traditional design-bid-build projects the role of the architect may vary but often it is their job to be an agent to the owner to make sure that the design intentions specified in the drawings and specifications are met to the owner's satisfaction.

The process of converting a design solution into an industry standardized bid package involves collaboration between various design architects, design engineers, and other consultants inseparable with a variety of representations. While the design is in its loose, conceptual phase sketches and rough physical models are used to articulate and share ideas between architects. As the design becomes more structured, the building is documented using 2D CAD (e.g., AutoCAD™). Using a standardized 2D tool allows other professions (e.g., structural engineers) to interface with the architects and to critique, assess, and add detail to the building design. Examples of the primary visual representations include sketches, physical models, and 2D CAD (e.g., AutoCAD™). Textual representations include lists, spreadsheets, and detailed specifications of materials. Once the general contractor is selected the information from the bid package is used to develop detailed *shop drawings* which show specific installation and construction details needed by the sub-contractors. Shop drawings are then approved by the architectural design team to ensure that the meet the design standards and intent. Information exchange between parties is typically guarded as each party is sensitive to providing any information that may be interpreted as misleading and used in future litigation. Architects, therefore, are generally guarded about the releasing of too much information in order to avoid liability from mistakes that may later be made during construction. In other words, architects hope to provide design intent but not specify how to actually construct, unless the method is essential to achieving the design intent.

AEC Projects Differ From Manufacturing and Product Development. AEC projects differ from manufacturing and product development work where design and construction activities take place. The characteristics of AEC projects include "immobility, complexity, durability, costliness, and high risk of failure" (Nam and Tatum 1989, p. 522). Construction is a location specific operation that does not typically take advantage of mass production system benefits and draws upon a significant amount of localized labor for each project. Completed construction projects are typically large investments for clients. The final product is usually expected to be safe, functional (or meet other client needs), and long-lasting. The customized nature of construction also implies that the owner of the eventual product "initiate and exert influence both on the design and construction process from the beginning to the end" (Nam & Tatum, p. 522). These characteristics are typically viewed as inhibiting much of the innovation within construction. According to Barlow, (2000) the customized and project based process also hinders organizational learning, standardization, and innovation in the construction industry. The high cost structure and high awareness of public safety results in conservatism from buyers and producers (Nam & Tatum). Cost, safety and reliability are the most important issues that focus the industry toward an exploitation and specialized focus.

Despite the above challenges, the AEC industry robustly takes on an enormous variety of projects. In order to do so, localized practices and interorganizational coordinating mechanisms in AEC have become routine and standardized. These standards form an infrastructure upon which the industry operates. Firms have made investments in technologies, tools, and management that in turn reinforce and strengthen the connections between one another and the tools and methods employed. At a high level several observations can be made in terms the standardizations in the industry. First, the level of complexity of the building has become more standardized in terms of the overall conception of what a building should be and the materials used to construct it. Second, the work practices within, between, and across the collaborating organizations has grown increasingly institutionalized. Fear of litigation and protecting ones own interests had led to guarded information sharing practices. For example, the means of representing buildings between architects and contractors relies upon standard 2D drawings with written specifications. The drawings contain sufficient detail for contractors to coordinate the activities of sub-contractors that translate these representational details into material work to produce the building. Architects dislike sharing the too much information with contractors for fear of becoming liable for mistakes during construction or time and budget overruns.

Data Collection & Analysis

To illustrate how to expand the problem space we draw upon case study data from architects, engineers, and contractors. To describe the AEC background and other case material, we are informed by data that range across more conventional firms, firms transitioning to newer design technologies, and Frank Gehry & Associates and others who are currently at the cutting edge of IT use in AEC. Along with case study data we also relied on industry publications and data to understand the basic relationships within the industry.

Our data collection began in 2002 and is ongoing. A major purpose of the study is to follow the impact of 3D CAD technologies as they cascade throughout the AEC industry. Over the course of these three years, we have collected 90 interviews from 58 different participants in 21 different organizations. We have also hosted a workshop on the digital transformation of the AEC industry with participants from architecture, engineering, construction, and academia. Interview data was collected using semi-structured interviews. One of the main emphases of the interviews was on understanding the use of the 3D technology and tracing the affects of such use within, between, and across the organizations. The majority of interviews were transcribed into text, others were partially transcribed, and others were audio coded using qualitative data analysis software. We also observed participants in meetings during the design and construction of projects as well as the construction process.

For purpose of this study, the data presented and summarized are a result of our participation in the interviews, reading transcripts, and categorizing related data into coherent narratives. We also discussed with participants and observed their use of different IT capabilities. In many cases the process involved discussing unique aspects to a project and then tracing it back to any related IT capabilities that were appropriated.

Achieving Predictability in Complex Design and Construction

In almost every AEC project designers face cost and time constraints. The need to achieve predictability of costs and time is apparent in both the conventional and more complex designs by Gehry & Associates. Without the ability to generate cost information early in the process designers risk investing too much time in designs that are not cost feasible. Developing cost information earlier allows designers to respond to cost constraints and modify the size, quality, or complexities. From a conventional architectural firm, one architect described the importance of estimate costs as follows:

> I can't think of one client going into a project that doesn't say, "This is our budget, this we must stick to this budget," and that's why we have our estimators constantly in dialogue with us because we want to make sure that the cost is controlled for our client.

The cost estimate is a function of time, material, and labor costs. These can vary based on the types of materials employed and the complexity of the construction. Quick cost estimates are typically based on heuristic calculations using the square footage (i.e., size) and the quality of materials in construction. More detailed cost estimates require accurate calculations of a detailed material list, the level of complexity associated with the building, the available resources in the localized market place, and the aggressiveness of the proposed timeline. The ability to apply cost estimating heuristics and standardized information is dependent upon the building following conventional guidelines in terms of it complexity of shape, types of materials, and interrelationships of the components and systems within the building. In conventional architectural design, rough estimates early in the process and 2D CAD later in design provides sufficient information to calculate quantities, provide material types, size, and infer constructability.

Maintaining Predictability in the Face of Complexity

A complex building, however, can render the key assumptions of cost estimating useless. The use of complex geometries from Frank Gehry's design has a rippling effect on determining material quantities, determining appropriate material types, and determining constructability. Trying to predict cost and time estimates can therefore be unlikely using the methods which are built upon the assumptions of standardized materials, labor, and time to construct.

According to the designers a principal reason for employing sophisticated 3D CAD tools is to enable predictability of a much more complex building. A project manager, Fred Johnson[5] described the need for CATIA™[6] the primary 3D CAD application employed by Gehry & Associates as follows:

> The reason is because CATIA makes the whole process and the whole method to build it somewhat *predictable*. And that's what all our processes are looking for. We give prices before we build. Let's say you build this in a country that you pay them as they go. And you figure things out as they go. You wouldn't need the computer at all. You would just pay them for their honest effort every day and you pay for the material used. And the client doesn't care how much it cost in the end. It's just it took so many days, it takes so much materials, here is the profit. That's how cathedrals were built. That's how Baroque was built, that's how Gaudi built. That's how most of the stuff in the world was built. You don't need computers for that. But if you need to predict, if you need to give somebody, say, here is what you need to do. Give me a guaranteed price that you will not exceed. You cannot do this. Because it is too complicated to document on paper. Without CATIA it would have not been possible to do it.
>
> For our financial structure, we need to inject predictability and the only way to inject predictability, you can only do it with computers, on a project that complicated. But there is nothing about the building that is special enough that it couldn't be built without computers. There

[5] Names of participants and companies have been changed except for the mention of Gehry & Associates Architectural firm.

[6] CATIA stands for **C**omputer **A**ided **T**hree-Dimensional **I**nteractive **A**pplication. It was developed by Dassault Systems originally for aeronautical design beginning in the 1970s. It is widely used within the defense (e.g., Boeing), automotive (e.g., Daimler Chysler), and shipbuilding industries. Gehry & Associates has recently (2004) started Gehry Technologies which has modified CATIA for architectural design based on their experience with CATIA since 1991.

> is not. But you would have to be there all the time, the engineer would have to be there, and the client would have to be okay to pay whatever it takes, from point one until you are done.

Jack Anderson, a Gehry & Associates partner, also discussed the need to achieve predictability in understanding the behavior of shaping metal in various ways as follows:

> A lot of what we did on this building, a lot of what was done on this building in terms of the exterior metal is out of a mechanical program. It's not an architectural program. It's not even an aerospace program. It's a mechanical design program, but it had certain functional features that we needed, that we could use. We wanted to be able to develop and unfold surfaces, *predict* the way we could shape the metal and, and you know, we had very specific ideas. But the ideas about how to build it existed before the software. I remember software was just brought in to take care of those, each of those operations.

From Anderson's commentary, we can appreciate the thoughtful adoption of CATIA to solve particular problems they faced. Johnson's comments reflect the larger need to develop fiscal and schedule predictability. The adoption of CATIA to aid in making the project more predictable, however, is not straightforward as simply using the software to do complex equations. Assumptions of constructability and types of materials were thrown open to debate. Further, the ability to predict time and cost would be dependent upon answering these questions. The complexities of the design had altered the standardized methods of construction that builders were accustomed to. The use of 3D CAD therefore, was expected to have far reaching implications in order for it to at act as indirect catalyst or a direct medium by which these assumptions could be reconstructed.

New Means and Methods for Construction: Case Study Examples

Developing new practices in construction are the basis of three examples that we now present. As noted above, these are situated within the larger perspective of being able to predict the cost and timing of the design and construction of a building. Two examples deal with the Gehry & Associates project and the third is from the more traditional architectural firm. These examples focus on the challenge of developing means and methods for construction. Means and methods are concepts of how to assemble or build various aspects of the building. Determining means and methods in advance of the construction is important in order to come up with reliable estimates for costs and time to complete. In the most standard projects, means and methods are simply applied to the design of the building. However, a complex building can render useless the standard means and methods. The process of facing new design constraints with old means and methods can create a knowledge boundary (Carlile 2002). In three examples from our cases we explore how these knowledge boundaries are overcome and how IT capabilities employed.

Example I – Concrete Sub-contractor

Due to the sculptural form of the Peter B. Lewis Building design by Gehry, the underlying concrete structure consisted of curving and undulating shapes. The concrete sub-contractor, CSC, responsible for laying out the concrete was more comfortable with using a version of 2D AutoCAD software which had some 3D extensions, but did not have the same capabilities as the CATIA software. Therefore, compatible 3D extracts of the CATIA model were imported into AutoCAD in 3D to help determine how to create forms for concrete casting and at the same time calculate the necessary material quantities. The role of the formwork engineer was to develop shop drawings which would be more detailed than the architectural drawings he received. These drawing would specify how the concrete forms need to be assembled to achieve the proper cast of concrete. The 3D visualization and digital assembly with precise coordinates and measurements were both utilized in this process.

> And a lot of times the beauty with AutoCAD was you could do different isometric views and stuff and we put that right on our drawings because that was the finished product and we'd have point numbers for the field engineers who worked with the points and stuff, but still there was a picture of the curved item on the drawings so the guy would now, "well okay, so this is what it is supposed to look like, ok, I got an idea of where this panel here goes and where this forms is supposed to be set or at what angle this supposed to go at, and so forth." Basically just give the idea to the person building that portion of the job what it was supposed to look like.

Isometric views refer to different angles and views of the same object. The process of creating the forms required precise measurement data as defined by the "points" provided in the specification, however, because of the abstract shapes there was a need for visual information so that the field engineers could determine if they were building the forms correctly. The addition of the 3D pictures was a change from their standard representational practices for the concrete sub-contractor. The formwork engineer also mentioned that he spent more time going out to the field to understand how to design these types of forms in a way that would necessitate less radical change from those building the forms. Through this process a new communication emerged between the field engineer and workers. In response to the researcher's question about issues discussed with the field workers, the formwork engineer said:

> Absolutely. You know what worked though. These guys they educated themselves. 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, this coordinate. For awhile there we actually developed like a new terminology or a new communication process on the job where guys, we educated them, and they educated us. "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.

The shift to a 3D coordinate system from the standard 2D system was supported by new visual representations to help the field workers reestablish their processes. Insightfully, the formwork engineer recognizes that this shift was not just increasing the information flow or frequency but was actually a whole new language to convey the ideas from the design to the field.

Example II: Interior Framing and Drywall Contractor

Another example developing new means and methods comes from interior framing and dry-wall subcontractor, we shall call DWS. DWS was first brought on in the design development phase and asked to bid on and cost the framing and drywall for the building. They were originally given 2D drawings and were also able to look at the 3D physical model. They recognized very early that the task was highly complex compared to the traditional methods of framing and drywall assembly and finishing. According to a V.P. of DWS:

> When we got into the project, there was some concepts in the documents of what could be anticipated as far as means and methods but what we found was that the type of building or type of work we were gonna do had not been done before. So, we were pioneers in this thing all, of a sudden and we had to come up with means and methods to build it.
>
> In the beginning it was to be some sort of partnership [between the general contractor GC and DWS] more of a time material type project because of the complexity, and it evolved into a hard bid project in which we bid off of the 2D drawings. Our initial understanding was that the documents we had were the one's we were going to build by and then later in fact, the 3D CATIA came into play, which totally changed, in our mind, everything. Because what we were trying to figure out on drawings [2D drawings] all of a sudden became more of a reality.
>
> We were shown the models, you know the physical models, and so we could see that it was a very difficult project. But we were [originally] relying on the information in the documents to give us enough to build the job.

Based on the V.P.'s comment here, one might be led to believe that being introduced to the 3D model showed them exactly how to build it, by nature of it being a full blown 3D digital prototype. However, the 3D model provided by Gehry did not contain all of the detail of how to assemble the framing members, for example. The 3D model is not yet used as a full digital prototype as might be found in product development, aerospace, or automotive industries. But 3D visualization was essential for them to design, test, and eventually decide on a framing method. Again the V.P. of DWS stated:

> 2D is the standard. … But it wasn't complete. And when you're looking at 2D drawing you don't recognize that there's things that are incomplete. But when you get out there … and getting back in CATIA then you see that not everything designed here is going to work.
>
> What I'm referring to, in the architectural drawings, the 2D drawings, they will show a flat surface… They'll show lines that are supposed to be studs. Then they'll show a clip, they'll show another cut detail, with a clip anchored to the floor. And another cut detail with a clip anchored to the side of the slab. That's a framing concept. That portion was the simple thing and it worked. But then we got into the openings in an undulating position. How do you make that opening mirror the undulation exact? That was something that wasn't there. There was the architect that provided the concept with the bent stud but you cannot bend a stud in the surfaces that we had on the project because they flow, so to speak. And traditionally bending studs has to be on a radius. Now, what we know about the surfaces of that, there could be 200 different radiuses within a 20-foot line. So you cannot take a conventional framing member and provide that type of bending. First of all it fails for weakness and there is no means of methods to bend it to match all those arcs. So what we ended up having to do was create the shape in CATIA, have it extracted and put into an AutoCAD file, sent here. We would take the shape and send it to a local fab shop. We did CNC plasma cutting of sheet metal and we would assemble the part. And that's how we created the shape. But see those were things that we brought to the table that were not in the documents [2D drawings or 3D model]. Also, the undulating corners, you know where this profile's got two different surfaces coming together and to create that exact corner was another issue that was not defined in the document. There was a concept in the documents and we – that one was very difficult for us as far as I don't know how many ideas. I got all these books from sitting down making pictures and notes. But we had several different ideas on how to do it. And then finally the concept was used. Finally, I think I woke up in the middle of the night and wrote it down or something.

DWS did not have prior experience working with CATIA nor in any 3D programs. The V.P. of DWS also began to use AutoCAD more frequently and was able to navigate within the digital CATIA model. He stated:

> ...we've got some CAD people here. But CAD doesn't even come close to what CATIA can do. So, you know, there is no understanding of what we were about to find out. What we did realize though when we were shown the CATIA, we were shown how we were going to build the job. Because once you get the reality of the 3D which brings reality to the drawings, it definitely changed our perception of what we were doing and what path we were going to take to build.
>
> The 3D modeling program, and I'm going to use the word CATIA because that's the one I'm most comfortable with, it allows you to, as far as design or build or understand what you are building by far beyond any type of 2D document or AutoCAD, there is no…it's phenomenal. So, at the point of getting involved with CATIA, that like I say gave us a better understanding what the shapes were and allowed us to start applying concepts.

In order to work with CATIA changes to the way that DWS related to the architect and general contractor were changed. He said:

> What I did personally was go to Frank Gehry's office, and I would sit with the CATIA operator, who was a subcontractor to GC, and I would sit there with him and we would just try to come up with concepts on the computer. When we found concepts that we were comfortable with, which was an evolution of almost 8 months, then we came back to the field, did mock-up testing. Tested them for their strength, you know, would they pass what the structural engineers want to perform, the way needed to, and some of those things changed as time went. But that is the process we had to go through to start the framing.
>
> 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 spent some days 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.

In addition to the changes to the way DWS related to other firms, DWS also modified its internal practices. In similar fashion to the form work engineer who translated the complex information to something understandable by the field workers, the V.P. of DWS also attempted the same.

> All the binders and binders of paper that 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 this is what you did. We'd email the CATIA work I did back to the job so that they could see what I did. And then they'd tell me what I did wrong. Then what I did right. And then we'd bring that back here and do all this AutoCAD work 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. The problem was near the end, we had a system down that was quick and efficient.

Example III – Centralized Surveyor

During the construction process the General Contractor, which we will GC, decided to utilize a single surveyor for most of the sub-contractors. Traditionally, each sub-contractor would refer to the 2D plans to understand the location of their specific materials, pipes, electrical wires, etc… The move to the CATIA system changed this system. The complexity and unconventional shape of the structure complicated the process of simply taking measures from multiple fixed locations. Using the 3-D coordinate system x, y, and z coordinates were available for most any position in the building. These points were taken directly from the 3D model and then given to the surveying sub-contractor. In the following interview an employee from GC discusses the rationale behind moving to a 3D coordinate system:

> First of all, I'd like to add some great, you know, demonstrative reasons for which we did that [used a centralized surveyor]. Number one is we figured that they wasn't gonna be able to get there. I mean we did it for the reason that number one we didn't think that they [sub-contractors] all could independently, it would end in chaos. Have them all independently get to a level of technology within a particular geometry of this building.
>
> Some of our guys were capable of doing it. We let them do it. CSC's [concrete contractor] being one. They laid all their own work out, but we hired them early on in the pre-construction setting because they professed to be knowledgeable about it. Other people didn't. You know, we liken it to the fact we have 22 guys out there that were carrying this pool of money. We'll take this pool of money, draw it back in, get it more reasonable. Control the information. And it was very much a control factor. We controlled that survey. It was our product through one of our consultants.

Moving from 2D to 3D reference system would have been a significant change for most of the sub-contractors as demonstrated in the following conversation:

> Sean:…We kind of turned it all upside down in this particular project at Weatherhead and we took back a lot of that responsibility for doing that work in the witness of this Jim Jones who is the surveyor who did all that work in the field, and we through this other individual provided that information to the subcontractors which a, was not something they were accustomed to, b, it was a shift in cost from their cost of figuring the project to our cost, and c, turned out to be the most reliable, the most accurate, the least problematic method that I've certainly used in 20 years. And I think Dan can say the same thing based on his experience. But we kind of turned the whole process round and the contractor's saying, what? You mean I don't have to do my own layout to a great degree? You're gonna provide that for me. And we were able to do that.
>
> Pete: First of all, I'd like to add some great, you know, demonstrative reasons for which we did that. Number 1 is we figured that they wasn't gonna be able to get there. I mean we did it for the reason that number 1 we didn't think that they all could independently, it would end in chaos. Have them all independently get to a level of technology within a particular geometry of this building.
>
> Sean: Right.
>
> Pete: And B, if they did do it, they could have five entities doing it. I could have five John trainees out there. So now I got five experts.
>
> Sean: Finger pointing
>
> Pete: All finger pointing.
>
> Sean: You still have the resolution of issues that come up. You never get rid of that responsibility. So we, you know, I wish I could say for some big, you know, heroic of reasons we grabbed that and took charge of it, but it was really we couldn't see another way.
>
> Pete: We decided to do it that way and we by that time believed in the process enough that we could do it accurately. And we were taking on a significant risk to do that. I think it's important to know that that process which you witnessed out there is not by no, by any means, a typical process.

In order to flexibly accommodate the new 3D coordinate system, GC decided to take on this risk to simplify the process for the sub-contractors. The example here demonstrates how the relational practices were rearranged. In effect, the sub-contractors still had to be familiar with the 3D coordinate system and work within its parameters, however, the system of applying it was centralized. Of course the trade off for GC Construction was that they now took upon them the risk to layout the 3D reference points accurately. The result of centralizing the survey points was a significant increase in the coordination efficiency between sub-contractors.

Typically the process of coordinating different sub-contractors might work something like this:

1. Concrete contractor puts up the concrete forms
2. Other trades (e.g., electrical and plumbing) need to prepare pipe and conduits that will go through the concrete.
3. Concrete contractor does not want iron workers that will put down the rebar to sit around and wait so they begin working.
4. Trades and iron workers are “stammering all over each other” (GC interview) to coordinate where the concrete penetrations will be.

GC attributed the 3D coordinate system and that data to consolidate the surveying process to the success of better coordinating this effort. Using this approach all of the coordinates for the concrete penetrations were marked very quickly and the trades put everything into place (e.g., conduit), resulting in less downtime for the concrete contractor, CSC, Inc.

Dave: And that was, and then it worked. It literally worked. Because we worked off the electronic information, we actually located the points within those studded wall cavities of the electronics. That point was known. It referred back to the grid. And then when the DWSs of the world went out there and put their studded walls in, they were working off that same reference point and that same grid system, so when they snapped their line, actually put the wall in, by God, that penetration's right in the middle of that wall. There wasn't any of this interpretation or you know, stretching of the chain, or anything. We just, it was a very you know smooth and orderly process. Within those traditional, not perfect, but

Dave: It's not perfect.

Dave: But you have a very high degree of opportunity for success. That's what it had. It had the opportunity to be perfect. In other methods you'd question whether you even create the opportunity to be perfect.

	IT Capabilities	Work Practices
Example I: Concrete	3D visualizations, simulation,	relational, representational, material
Example II: Framing System	3D visualizations, digital pre-assembly, simulation	representational, digital pre-assembly, relational, material
Example III: Surveyor	Computational, digital prototype, digital pre-assembly	cognitive, material, relational, representational

Table 2. Synthesis of case study examples

Discussion

We see how four dimensions of work practice associated with building design and construction were challenged: representational, cognitive, relational, and material. These four work practice elements did not change, however, independently from others and there was no direct causal impact between IT use and changes in these practices. Rather they all were mutually adjusting as IT capacities were appropriated over time by different communities of practice.

Representational Practices

The representational practices were significantly changed when CATIA became the master model of the design and was used by the general and sub-contractors. 2D drawings were not eliminated but were usually generated from the 3D models. This relationship created a more isomorphic relationship between 3D and 2D than usually exists in a typical project. The IT capabilities of full visualization and precise 3D coordinate system were the primary capabilities that led to changes in representational practices. In several cases individuals acted as conversion points to take the complex 3D geometries and re-represent the information back into 2D for the benefit of those whose material practices depend upon 2D representations. These efforts of converting information were intentional. However, there was a significant amount that could not be converted and therefore many had to representational practices. Further, the move to a 3D coordinate system was a dramatic change to representational practice and had effects on the way that workers did the actual layout of the structures.

Relational Practices

The relational practice changes were evident in all three examples. Some changes included new ways of communicating and coordinating internally as well as new relational forms between sub-contractors and the designers. Relational practices seem more difficult to determine whether they can be more attributed to the adoption of 3D capabilities or whether without them 3D could have been appropriated. The fact that there was a single master model and isomorphic representations that resulted from this master model may have created more tightening of the relationships between individuals with different backgrounds. This also highlights the boundary object capacity of 3D to be highly flexible to multiple parties yet robust across the groups. This form of robustness, however, is different than is usually thought of when dealing with other types of boundary objects. Robustness usually is a result of the vagueness of the object, however, here it results in the preciseness of the object in modeling a real artifact.

The design assist process is a relational practice, and one that Gehry tries to employ in all of the current projects because they believe that it is essential to figure out the constructability of many of the building challenges. Regardless of the 3D capabilities more pre-construction activity would be needed to come up with appropriate means and methods. There does appear though that some of the new relational practices were simply a result of needing to utilize information from CATIA by working with other parties. DWS for example worked with GC and Gehry personnel to utilize CATIA; they did not have their own license of CATIA.

Cognitive Practices

An example of cognitive practice change was evident when The V.P. of DWS discussed how his perception changed when moving to 3D from 2D—he could see literally and understand cognitively how it would be built. Using a 3D coordinate system also had an effect on the way that the building process was conceptualized. GC chose to use a centralized surveyor to minimize the amount of change that the 3D system created. Of course, cognitive aspects are perhaps the most difficult to analytically separate from other dimensions of work practices. Underlying new representational and relational practices are cognitive understandings of why and how to adopt the representations and coordinate actions. However, cognitive changes were apparent in the way adopted and the later discussed using 3D coordinate system terms not only the project where 3D was used but also to refer to regular 2D projects. The cognitive effort to change representational, relational and material practices was also evident. Comments by workers that they have never had to think this hard on a job were not uncommon. This should not interpreted to be that thinking did not take place previously, but rather the complexity of the building and the new representational systems created a dramatic cognitive shift.

Most all of the IT capabilities seem to relate to some of the cognitive shifts. Baba and Nobeoka discuss the role of 3D CAD in enabling cognitive processing that supports designing (Baba & Noboeka 1998). The capabilities mentioned by Baba & Nobeoka, full visualization, simulation, digital pre-assembly, and design validity, tolerance, and flexibility capabilities all enable cognitive changes because they enable a new representational system.

Material Practices

Lastly, the change of material practice of construction was evident through the new means and methods applied to making forms and pouring concrete as well as framing the interior wall system. The surveying techniques were a new material practice which affected other material practices during the construction process, such as how to layout the building. These material practices are clearly second order effects and the most removed from the IT capabilities discussed. There are examples of those in the field utilizing the 3D visualization to solve problems and understand how to building certain elements. These are made possible because of the changes to representational practices, cognitive understanding, and often new relational practices that make using 3D possible.

As noted four analytical dimensions of work practices discussed here have direct/indirect relationships and first and second order effects from the appropriation of IT capabilities. Separating out these aspects of practice is helpful to see that some IT capabilities are intended to make a difference to one analytical aspect of practice but possibly in an indirect fashion. For example, these examples share in common the need to effect material practices, however the IT capabilities are not new tools and artifacts that are supposed to directly manipulate matter. Relational practices as well are not directly affected nearly as much as in studies that focus on communication technologies. However, without relational practices changes it is unlikely that IT capabilities could have been adopted.

Limitations

Several limitations are apparent in this research. First, we have not validated our findings from the AEC to other industries to improve the generalizability. Second, the language and descriptions of IT impacts of work practices presented here are preliminary and may be less applicable once we move outside of the AEC industry.

Due to the nature of a case study research there are no control groups performing the same projects without the use of 3D capabilities. Therefore, we rely upon the judgment of those we interview and observe to give a sense of whether or not 3D created an impact on the project. To paraphrase a comment from one of the structural engineers, "This project was very difficult, but would have been even more difficult without 3D. 3D made it easier." Other limitations include the retrospective collection of data which relies upon the memories of individuals. From an IT impact perspective it is difficult at this stage to attribute the relational changes between the AEC participants to use of 3D CAD alone when considering the complexity of the building. It is clear however, that all participants agree that the project would not have been feasible without 3D when considering the fiscal and temporal constraints. What we see both by CSC and DWS is that boundary spanning individuals are able to work with the complexity of 3D representations and come up with a process that can be converted into something understandable and efficient enough so that processes are not completely abandoned. Given the constraints to predict and come up with beforehand the means and methods, 3D technology was seen as both a solution and a barrier to overcome the challenges presented by the complex designs.

Conclusions, Implications, and Future Research

The purpose of this study was to expand theoretical constructs with which IT impact is conceptualized in IS research. While the IT impact research is recognized to be one of the core elements within the IS research (Benbasat & Zmud 2003), lexicon and conceptual frames which are applied to understand this set of phenomena may be too restricted to provide valuable insights at the impacts of micro level IT appropriation on organizations and communities. Yet, this adopted perspective of IT impact must reflect the increasing complexity of organizations and ubiquity of IT use.

We chose to approach the issue of how to conceptually frame the question of IT impact by opening the black boxes of both IT use and work practices. Both of these elements have been treated through relatively rough proxies (e.g., investments in IT) and too generally as to add deeper understanding of the mechanisms how IT impact takes place. Our approach to opening the black box was to focus on specific sets of generic IT capabilities provided by new 3D technologies. We suggested four pervasive and constitutive analytical dimensions - representational, relational, cognitive, and material- for analyzing work practice. These four dimensions are not exhaustive but have been derived both from our analysis of data in AEC and review of extant literature on work practices. It is possible that new dimensions for analyzing work practices may emerge in other industries or through further data collection in AEC (e.g., coordinating practices). Our purpose in proposing these classification schemes was not to challenge the existing theoretical explanations of how an IT capability might change or reproduce existing work practice. Rather our purpose was to demonstrate that past research has not well captured the breadth and scope of how IT use and the mobilization of specific IT capabilities affects in multifaceted ways work practices.

Through vignettes chosen from the AEC industry we showed how IT impacts cascaded across organizations and separate work practices, both directly and indirectly. IT capabilities could influence one or multiple dimensions of work practice. Moreover, many times these capacities were drawn upon as intended to facilitate the change of other aspects of work practice which were further removed (e.g., material practice of construction), or that required mutual changes in many work practice dimensions. For example, 3D CAD offered a new representational system that was dependent upon changes in cognitive and relational practices to be effective. In turn, this ensemble of work practices could enable new material practices to emerge. Another contribution is that the current research focuses on a highly dynamic and innovative context in which changes to work practices take place in temporary and differentiated interorganizational context, which differs from other studies of work practices that focus on more gradual work practice reproductions and changes[7]

We suggest several future research directions as a result of this work- not in any particular order):

- A journal based survey of the existing impact literature will help further substantiate the limited focus of IT impact research and the need to expand its problem space.
- Application and development of existing theoretical frameworks (e.g., social representations, structuration theory, actor-network theory) to this broader problem space.
- Further explore the systematic relationships of IT capabilities and various analytical dimensions of practice to provide to provide more potentially generalizable evidence for other contexts.
- Expand the research setting to other industries and to non-radically innovative project settings.

Expanding the vocabulary of IT impact studies by necessity creates a more complicated and risky venture for IS researchers in following the impacts of IT further down stream from the initial use and adoption. Following these trajectories of IT impact, however, appears inevitable when changes in core infrastructural systems (e.g., 2D to 3D representations) and the increased drive to create interconnectivity between IT take place. Information technologies are not just replacements of current manual or paper-based systems, but add different and non-existing capabilities to individuals and groups that may cascade with other impacts. In this sense they are quite different from first generation of IT systems. This emerging view is also more commensurate with the current distributed business environment in which IT has become ubiquitous and infrastructural.

[7] Both Orlikowski (1996) and Vaast & Walsham's (2005) contexts are those that describe gradual transforming change or metamorphosis. An AEC project is an opportunity to understand immediate and potentially rapid transformations of work practice.

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