Embedding Intentions in Drawings: How Architects Craft and Curate Drawings to Achieve Their Goals

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ABSTRACT

Based on ethnographic data collected at a global architecture firm over a one-year period, we describe the ways in which drawings are strategically created and curated by architects in an attempt to carefully craft their interactions and fulfill specific intentions with clients and contributors. We identify three strategies used by architects when creating drawings and reveal that the way these strategies are employed depends on the intended purpose of each drawing with a specific set of actors. This work builds on existing literature on the role of objects, such as drawings, for work across organizational boundaries and professional disciplines. We conclude with implications for CSCW and propose ideas for approaches and applications that better support cross-boundary and highly visual work involving multiple sets of actors and artifacts.

Author Keywords

drawings; architectural design; computer aided design; boundary objects; qualitative methods

ACM Classification Keywords

H.5.2. User interfaces: Interaction styles.

INTRODUCTION

Today's workplaces are filled with objects, including documents, folders, calendars, notebooks, and memos, among others. While objects are prevalent in almost every work environment, they are embedded in existing practices and often go unnoticed. Beyond simply using objects, it is common for individuals to create, curate and share objects. In fact, objects, defined as "artifacts that individuals create, measure, manipulate and work with in attempt to reach their desired end outcome" [7:446], play an important social role ranging from enabling communication to supporting negotiations. While many types of objects are appropriated across occupations and industries, based on our field study

of architects, we focus on drawings and the strategies employed by architects to create drawings for clients and other actors.

Most existing theory and research on the role and use of drawings focus on the interpretation of the drawings rather than their creation. While previous research has shown the importance of drawings in visual engineering cultures [14,15] along with the various ways they are used, interpreted and understood [4,7], only recently have scholars started to pay attention to the way in which drawings are intentionally created for different actors and purposes throughout a project [3]. As a result, even though drawings are created with a particular intention and often with a recipient in mind, we know little about the intentions embedded in drawings or how these intentions shape the strategies employed when individuals create, adapt or distribute them. Based on an in-depth ethnographic study of the use of artifacts for collaboration in a global architecture firm, we identify the specific strategies used, as well as how and why these strategies vary across different sets of actors.

The Role of Drawings

Drawings are frequently recognized for their role in structuring the work process and creating the final product in visual engineering and design work environments. This important technical role has even led drawings to be described as "the building blocks of technological design" [14:468]. Specifically, drawings are viewed as artifacts that help guide the work process and are eventually used in the construction of the final product [4,15,21]. Designers, for example, manipulate drawings to explore design alternatives by transforming shapes and locations, changing viewpoints and using multiple drawing types and media [11]. Similarly, graphic designers create and use drawings to create an understanding of their design, make decisions, communicate with different stakeholders and eventually sell their designs to clients [18].

In addition to their technical role, drawings have been found to play an important social role in engineering and design work. Specifically, research has shown that drawings enable communication and coordination, structure interactions, organize collective knowledge, solve problems and even influence who can participate in a task or collaboration [4,6,7,9,14,15,19-22,29]. Henderson's (1991) ethnography of engineers designing a new turbine engine

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package, for example, precisely captures the important social role of drawings in the visual culture of the design engineers she observed. Henderson illustrates the way drawings were used to structure interactions, coordinate work practices, mediate conflicts and enable collective cognition. Another ethnography by Vyas and colleagues showed how designers create and use a variety of different drawings for a range of activities, including design exploration, communication with other designers and coordination [29]. More recently, Christensen (2013) described the range of different drawings and representations that get created and used throughout the building process and their importance for coordination, starting in the initial planning and design process all the way to the final construction of the building [9].

Enabling Cross-Boundary Collaborations

Fundamental to the social role of drawings is their ability to enable collaborations across professional and organizational boundaries [17,18,21]. Specifically, drawings support social processes and enable coordination among people working across disciplines, which often leads drawings to be categorized as boundary objects [25]. An object becomes a boundary object when it can translate and transform meaning across work communities [20]. Boundary objects thus allow coordination among different social worlds in the absence of consensus by allowing knowledge to permeate professional and organizational boundaries [19,21] and enabling individuals to tailor objects for local use in their own community of practice [1,27]. For these reasons, boundary objects have been recognized for their ability to facilitate “conceptual knowledge work” across “distinct communities of practice” [19:6].

As mentioned above, many scholars have documented how drawings can serve as boundary objects [3,4,14,15,21]. Henderson [14] was one of the first to argue that “the capacity of engineering sketches and drawings to be flexible for various uses and users and thus to facilitate differential readings qualifies them as boundary objects” [14:450]. Since then, studies of boundary objects have illustrated how individuals across disciplines and communities of practice use drawings to work together, communicate and coordinate their work. Engineers and designers, for example, rely on drawings as a medium to coordinate diverse groups of actors and professional competencies throughout the phases of a project [24].

Strategically Creating Objects

Given that a “shared syntax or language of representing knowledge at the boundary” [7:451] is required for something to be categorized as a boundary object, it is important to understand the setting in which boundary objects are used and how they are created to enable the flexible representation and transfer of knowledge. Since the idea of boundary objects was introduced, however, most research has emphasized the different ways in which the same object can be interpreted depending on the individuals

interacting with it. As a result, the focus of previous research has been on the inherent flexibility and ability for multiple interpretations of boundary objects rather than on how these objects are created and manipulated to establish a shared understanding with different audiences.

The emphasis on the object’s malleable interpretations, moreover, suggests that boundary objects are flexible enough to be interpreted by a wide range of individuals. This perspective overlooks many of the technical and social affordances and constraints that objects, such as drawings, introduce [8,19]. Without a shared understanding of the knowledge represented, drawings fail to enable collaboration among diverse sets of actors [16]. Findings from Bechky’s [4] ethnography of engineers at a semiconductor equipment manufacturing company, for example, revealed that while engineering drawings were assumed to be the ideal medium for communication, the assemblers lacked both contextual knowledge regarding the production of the drawings as well as formal knowledge of how to read the drawings. Likewise the engineers did not have a concrete understanding of what the objects depicted in the drawings would look like or how they would function when they were actually assembled.

Previous explorations of boundary objects, furthermore, assume that the meaning of objects develops emergently throughout cross-boundary collaborations rather than strategically before or at the time objects are created [3]. According to Barley et al., [3], this stance “ignores the possibility that people may bring to cross-boundary settings objects that they created with the specific intention to guide their communication partners toward a particular set of meanings” [3:281]. Specifically, in a study of automotive engineers, they documented how the intent of the engineer creating a boundary object influences the form the object takes before the object ever enters a cross-boundary interaction. They found that engineers purposefully shaped boundary objects to either be more ambiguous or be more clear, depending on whether their purpose was to foster healthy interactions or expected resistance to their ideas, respectively. As a result, they argue that “understanding the ultimate meanings associated with boundary objects and how those meanings develop, therefore, would require that we begin to pay attention to the object not at the moment it enters cross-boundary collaboration, but at the time when it is created” [3:281].

Taken together, while the boundary objects literature contributes to our understanding of the social purpose of drawings along with the social processes they support, it does not provide conceptual tools for understanding how drawings may be intentionally created and used for social purposes, especially when the intentions of the drawings’ creators and the role of the individuals involved with the project are dynamic. If we hope to fully understand the social role of drawings, we need to understand the intentions of the individuals creating the drawings and the

strategies individuals use in creating them. We therefore seek to answer the following questions: What social purposes and intentions are embedded in drawings? In what ways do drawings get created to support these social processes? How does the social role of drawings along with the intentions architects have with different types of actors influence the types of drawings that get created and used?

METHOD

We conducted a qualitative ethnographic study of GlobalArch (a pseudonym), a large multinational architectural and design firm. Over a period of one year, we collected data through on-site observations and informal interviews with the architects and designers at one of GlobalArch's North American studios. Each observation lasted around 4-5 hours, during which we watched informants as they worked at their desks, attended meetings, conference calls and design reviews, and we ate lunch with informants and attended social gatherings. During our observations, the architects frequently talked to us about what they were doing and why they were doing it. This allowed us to develop a deeper understanding about the purpose and intent underlying their interactions and activities, what they were doing at that time and the drawings they were creating or working on.

While the duration, scope and complexity of projects at GlobalArch varied depending on the project, client, budget and other factors, the structure of the work process we observed was similar and consistent with the process used in the architectural design industry. Specifically, the design process used at GlobalArch consisted of five phases. Projects began at concept design and then subsequently moved to schematic design, design development, construction documentation and construction administration. At each phase, the nature of the work and decisions became much more detailed and harder to change.

Our data collection resulted in a total of 84 observations of 32 architects working on 17 projects. We observed projects across all five phases in GlobalArch's architectural design process. Specifically, we conducted 23 concept design observations, 20 schematic design observations, 32 design development observations, 20 construction documentation observations and 15 construction administration observations. Occasionally, we observed more than one project or phase during an observation. Given that many of the activities and interactions we observed took place on the computer, we requested screenshots and digital copies of files, drawings, emails and electronic documents with which they worked. We also made photocopies of paper documents, such as annotated drawings, sketches, meeting notes and other scribbles and calculations that were jotted down on scrap paper. Finally, we took photographs of physical prototypes, models of buildings and samples of materials. In total, we collected over 600 artifacts. Incorporating all of these data sources into our field notes allowed us to capture detailed descriptions of the behaviors,

activities, interactions, intentions and actions that occurred along with the physical and digital objects that were created, used and shared.

Data analysis followed a grounded-theory approach [10,13], which consisted of iterative coding using the ATLAS.ti software program. We started by open-coding to capture themes, activities, interactions and behaviors. Analyzing the coded passages suggested that drawings played a critical role in a majority of the work practices and interactions and that they took many different forms throughout the phases in a project. After identifying this theme, we moved to axial coding, which was more focused and structured around specific concepts related to drawings and how they evolved through the architectural design process. Throughout our analysis, we reviewed relevant literature to understand our preliminary findings and revise our coding scheme. We then did a final round of coding on the subset of data related to drawings using our final coding scheme. Our analysis revealed that the strategies used when creating drawings was heavily influenced by the architect's intentions with respect to the set of actors for whom the drawing was created. As described in the following section, the social role drawings played was not a passive byproduct but rather resulted from the intentions and design strategies employed by the architects.

INTENTIONS AND SOCIAL PROCESSES SUPPORTED BY DRAWINGS

At GlobalArch, drawings supported many social processes and were at the core of the architect's communication and coordination practices with clients and external contributors. Drawings served as a medium that allowed the architects to get commitment, seek approval and receive input and feedback from both sets of actors. The drawings also simultaneously helped limit the extent to which clients and contributors requested changes or introduced conflicts with the design intent for the project.

The architects often used the term "design intent" to refer to the overarching vision and design choices based on the goal of the project and the needs and criteria set by the client. Specifically, the design intent, which was established early in the project, resulted from many interactions between the client and the architects. During these interactions, the architects worked to understand and interpret the needs of the client and then translate the vision in a way that resonated with the needs of the client, including their budgetary constraints. Throughout our observations, it became clear that the architects viewed their stewardship of the design intent as one of their core contributions to the project and worked to preserve the design intent on behalf of the client.

The desired outcome of the drawings, we observed, was to strategically represent details of the project in an attempt to help clients and contributors understand potential options, provide feedback and eventually commit to one option that satisfied the client's needs and requirements reflected in the

design intent. Ultimately, the architects wanted to provide clients and contributors with drawings that were sufficiently detailed so that the actors making the decisions could understand them, but that preserved the vision and design intent for the project.

Clients

Throughout our observations at GlobalArch, the architects worked with many types of clients all over the world, including CEOs of global organizations, government officials and university leaders. While GlobalArch's clients differed widely in terms of their involvement, priorities, experience and needs, they were similar with regard to their influential role and how the architects perceived them. Specifically, the role of clients was to give feedback, request changes, sign off on details and make budget decisions, all of which shaped the eventual implementation and construction of the plans detailed in the drawings. Lisa, an architect we observed, explained that clients ultimately had the final say on decisions:

Lisa said that although the client, CliCorp [pseudonym], has the final say on all decisions, GlobalArch can submit a design or plan that they feel is best and up to "GlobalArch standards." Lisa said that GlobalArch will "of course" always work with the client and cater to their preferences, but sometimes GlobalArch will suggest an alternative that the client may not ultimately choose.

This theme was recurrent throughout our observations. Specifically, it became clear that the architects had to carefully manage the needs of the clients while simultaneously guiding them toward decisions that preserved the design intent. As a result, the architects created and used drawings in such a way that allowed them to both cater to the preferences of the clients as well as nudge them in the direction of decisions that were aligned with the design intent established at the outset.

Contributors

Contributors from outside of the organization, such as consultants and contractors, played a different role than clients and actively collaborated with the architects to produce drawings and advise on details related to the contributor's expertise and responsibilities. While there were many types of contributors, most project teams consisted of consultants, contractors, professional renderers, permit reviewers and local architects.

Similar to clients, contributors varied in terms of their expertise and involvement throughout the project. Among the contributors, contractors and consultants were the most heavily and consistently involved throughout a majority of the phases compared to the permit reviewers and local architects who were involved during particular phases when their expertise or approval was needed, such as during the permitting process. Even though which contributors were involved fluctuated throughout the project, the architects'

underlying intentions and expectations with regard to the role of contributors remained the same.

As we describe below, the architects utilized drawings to communicate, coordinate and structure interactions with the different contributors. They also relied on drawings to convey and preserve the design intent to make sure the contributors understood and worked to successfully achieve the vision they articulated.

STRATEGIES EMPLOYED

Throughout our yearlong observations, the architects created many different types of drawings ranging from hand sketches to professional renders. Even though only 2D detailed drawings were ultimately used to construct the final building, the drawings took many forms before they were finalized in 2D. This was mostly due to the various actors involved in the project, the type of details that had to be included, communicated and decided upon, and the range of purposes and social processes the drawings supported throughout the design process.

While a functional or technical perspective on the role of drawings might predict that the complexity and amount of detail in the drawings both increase throughout the project, we observed that the design strategies employed at GlobalArch were driven by the creator's intention with respect to a specific set of actors rather than the project phase. In fact, as the number of details that needed to be included in drawings increased and became more difficult to communicate, it became increasingly important for the drawings to include only the details necessary and relevant to the intended set of actors for whom they were created and that supported the architects' communication goals at that point in time.

We identified three strategies employed by the architects when creating drawings. First, depending on the audience, architects created drawings that were either largely conceptual or largely technical. They also determined the resolution of details which ranged from including a few, high-level details to many, specific details. Finally, architects managed others' focus of attention by curating what details were provided or emphasized in the drawings. All of these strategies and the way they were employed depended on the intentions of the architects and whether the drawings were created for clients or contributors.

Conveying Conceptual vs. Technical Content

As mentioned earlier, the architects created, used and shared many different drawings throughout the architectural design process, including 2D plans, 3D models, professional renders, hand sketches and conceptual diagrams. We categorized the content of drawings as either conceptual or technical depending on how the information and details were visually represented and communicated.

Conceptual drawings, which included 3D drawings, professional renders, abstract diagrams and basic color pencil sketches, did not require specific knowhow or

expertise to understand and were therefore widely accessible and open to many different interpretations. Furthermore, by visually representing and simplifying complex technical details, conceptual drawings facilitated certain coordination and social processes that did not require knowledge of the underlying technical details. Conceptual drawings, however, contributed little content to the details required for the final 2D drawing deliverables.

Technical drawings, on the other hand, consisted of 2D drawings, 3D models with dimensions and hand sketches with technical details, all of which were typically more rigid in terms of how they could be interpreted (as noted in [3]), especially without the appropriate expertise. These drawings helped facilitate coordination among individuals who understood the complex technical details and the types of lines and symbols used by the architects.

The analysis that follows elaborates on the role and intended purpose of conceptual and technical drawings, particularly with regard to the individuals for whom the drawings were created. It was clear from our conversations with informants and from our analysis that most of GlobalArch's clients did not understand 2D drawings and prioritized aesthetic and visual details while contributors, on the other hand, needed the technical details represented in 2D drawings to do their jobs and focused almost entirely on the technical details. In a later conversation with one of our contacts at GlobalArch, he captured this by explaining that drawings for the clients need to be "on the surface" whereas drawings for contributors need to be "below the surface" because of the different roles and expertise they each have in the project. Therefore, to satisfy needs of the different actors, the architects generally created and used *conceptual* drawings when they were intended for *clients* and *technical* drawings when they were intended for *contributors*.

Clients

A majority of the drawings intended for clients consisted of conceptual content that was visually and aesthetically appealing. Given that the client had to approve a majority of the decisions related to the drawings, the architects presented the information in a way that enabled the client to understand their designs. These conceptual drawings, such as diagrams, high fidelity renders and 3D models, contributed little to the final 2D drawings and were time consuming and expensive to produce, but were vital to architects' work and interactions with the clients.

As mentioned earlier, clients typically struggled to understand 2D drawings or drawings with technical details, which were difficult for them to visualize and interpret. For example, Grant, an architect we observed, was working on a 3D drawing in Rhino, a computer application used to create 3D models. He explained that he created renderings for the weekly meetings with the client to show the client the progress that was made. According to Grant, the client did not react well to diagrams or screenshots of the model

in Rhino, where everything is grey. Grant was therefore working on making the "honeycomb texture" on the glass surface of the building more reflective in addition to making several other aesthetic changes to the drawing to help the client better visualize the progress made.

The architects also created conceptual drawings for clients in attempt to enable and steer decision-making by helping clients see their environment in new ways. Marty, a senior architect explained to us the importance of architects advocating for their designs while simultaneously responding to the needs, perspectives and constraints of the client and other actors. The architects, therefore, strategically created and used conceptual drawings to effectively communicate the benefits of their designs.

For example, we observed Marty working on conceptual drawings to include in a solar analysis presentation for the client. The goal of the presentation was to strategically communicate details related to the position and impact of the sun at different times of day and year. Marty's intention was to garner support and convince the client about the vertical sun panels he was proposing in his design. Marty explained that if GlobalArch was able to "convince the client of the logic" behind adding vertical shading, then it was "easy." Another way conceptual drawings were created and used to persuade clients and influence their decisions was by using drawings to tell the project's story. For example, as Karl, another architect, was working on 3D schematic designs for the client, he mentioned that each building is "supposed to have a story" and explained that the schematic designs he was working on were "useful to get a client excited."

Conceptual drawings were also intended to educate the client by helping them understand the market and the value that the project could contribute. This required that conceptual drawings be strategically created to present the architect's concepts and overarching vision in a way that was visually appealing and easy to understand. During one of our observations, Charlie, a senior architect, was working on a conceptual drawing for the client. According to Charlie, GlobalArch "has thought about and identified different types of visitors that might come in through the front doors." The conceptual diagram was intended to help the architects illustrate their logic and vision for the central common area in the hotel they were designing. While the more technical Rhino drawing illustrated the layout of the space from several angles, it failed to communicate and visually represent the contextual factors, such as how visitors might enter and use the space, which were equally, if not more, important to the client.

In addition to persuading clients to approve the proposed designs, the architects created and used conceptual drawings to convey the look and feel of the building in context. The drawings in later phases, for example, aimed to help clients visualize different options for specific details, such as materials, colors and finishes, and

understand how their decisions would look upon completion. For these reasons, as highlighted in the following excerpt, conceptual drawings continued to be important throughout the project, especially later when the complexity and number of details increased:

Gary mentioned that the client “sees all of the design development documents but they don't understand” how the AutoCAD design development drawings will actually look. He said they are working with a contractor to create 3D renderings of the design development documents to show the CliCorp [pseudonym] leadership how their proposed changes will look.

Conceptual drawings, therefore, were fundamental to the way the architects communicated and interacted with clients. They tended to be high fidelity renders or 3D models aimed at helping the client to understand the design vision and supporting decision making by enabling clients to visualize the building and its details. Overall, the conceptual drawings enabled the architects to represent project details in a visually appealing and interpretable way, both of which were necessary for the architects to excite, persuade and satisfy their clients.

Contributors

Unlike the high fidelity drawings and renders produced for clients, drawings created for contributors were often highly technical, including details drawn to scale and important specifications, such as dimensions and materials. Most of the drawings created for contributors were intended to help coordinate decisions, although later in the project the drawings also helped architects negotiate changes as well as clarify or revise project details. As a result of these intentions, drawings for contributors typically consisted of complex 2D drawings with dimensions and annotations along with documentation, such as specs and contracts.

One architect, for example, explained how certain patterns on the tracing paper sketch she was creating for the structural engineer described the material that would be used. She then pointed to a symbol on her tracing paper and said it denoted concrete. During another observation, Lisa and Gary were working on a 2D AutoCAD drawing that was created for the lighting contractors. In this particular example, Lisa and Gary shared the drawing with the lighting contractors who then revised and added to it. Lisa mentioned that the lighting contractor moved some lights based on their lighting calculations, and re-specified certain lighting fixtures. The technical details in the drawing enabled such a collaboration.

In later phases of the project, it became more difficult to make changes, especially substantial ones since most of the materials had been ordered and the design process was nearing completion. Therefore, rather than using the drawings to coordinate, collaborate or seek feedback from the contributors, the technical drawings were more often used to negotiate decisions and changes. For example, we

observed Scott closely examining a document the consultants had attached to an email they sent him. The document had images of the 1st and 2nd floors for the project along with red notes throughout. The red notes in the figure were comments from the consultants regarding details they had changed as well proposed revisions for details they had not yet changed. Scott explained that at this phase there is a lot of back and forth between the architects and local consultants addressing concerns or slight modifications, which GlobalArch either approves, revises or to which they propose alternatives. These revisions might relate to measurements, materials or other details.

In sum, the technical drawings served both functional and social purposes with contributors. Specifically, as described above, many of the drawings created for contributors consisted of highly technical 2D drawings that contributed to the final 2D drawings in some way, but simultaneously aimed to aid the collaboration by clarifying details, facilitating decisions, and enabling revisions.

Choosing Resolution

In addition to varying conceptual vs. technical content, the architects at GlobalArch strategically created drawings with different levels of resolution. We use the term *resolution* to describe the number of details included. The resolution of drawings ranged from low to high depending on the actors involved and intended purpose (see Table 1). Low resolution drawings included few high-level details compared to high resolution drawings, which contained many precise details. Conceptual drawings were created to be both low and high resolution, with high resolution drawings being fully fleshed out and low resolution drawings being more of a sketch or outline of an idea. Similarly, technical drawings were sometimes low and sometimes high resolution, depending on how many technical details were included.

Specifically, our findings reveal that while the nature of the work and decisions became increasingly more detailed at each project phase, the architects strategically included more or fewer details depending on their intentions with the client or contributor for whom the drawings were created. As a result, drawings with low and high resolutions were created during all project phases rather than getting increasingly higher in resolution as we had expected.

Clients

As mentioned earlier, the architects at GlobalArch generally created more conceptual drawings rather than technical drawings when interacting with the client. These were sometimes low and sometimes high resolution. Low resolution drawings for clients tended to consist of abstract representations with few details. These drawings took the form of hand sketches, images and conceptual diagrams, such as visualizations and other types of illustrations. High resolution conceptual drawings intended for clients, on the other hand, included many realistic details and provided a more accurate illustration of how the buildings might look

when built. These drawings, which at times were described by the architects as “sexy” and “seductive,” typically took the form of 3D models and professional renders.

The architects used low resolution drawings to communicate rough ideas or details to the client, which helped the architects get initial feedback and commitment from the client (see Table 1). Furthermore, given that clients were often unclear on what they wanted, architects created low resolution drawings in attempt to reduce the chance of confusing the client and prevent problems later. Architects also created low resolution drawings with the intention of uncovering and correcting erroneous conceptions and moving the client toward committing to an idea, which in turn narrowed the scope and set limits to the project. Karl, an architect we observed, described a PowerPoint presentation created for the client, which included slides that contained diagrams and photographic images of various malls, outdoor shopping areas and upscale food courts. According to Karl, “clients will say that they want a ‘retail space,’ so we think they mean Steve Madden and Nike, and then they see it, and they’re like, ‘no, no, no, no!’” These early conversations supported by low resolution drawings ultimately helped the client and architect figure out a mutually acceptable design.

High resolution drawings for the client, in contrast, were intended to visually represent and communicate the building’s “story” and design intent in a way the client could understand (see Table 1). Specifically, high resolution drawings were used to help the client envision and get excited about how the final building would look. As described in the excerpt below, while high resolution drawings were difficult and time consuming to create, the effort was worth it because they were valuable to the clients and simultaneously allowed the architects to craft how project details were represented and communicated:

Grant mentioned that the “client does not read drawings like architects, so they need something flashy.” He also added, as “we try to appease the client,” this requires “more details,” which leads to “more rendering.” Grant continued, “It takes a lot of energy. It’s not easy to create renderings.”

Most of the time, high resolution conceptual drawings were created for clients with the intention of aiding decision making and seeking approval. Given the complexity of many of the project details and the challenges involved with interpreting and visualizing technical drawings, high resolution conceptual drawings enabled the architects to provide clients with realistic visuals to make decisions and approve details and changes. The excerpt below from an email sent to Gary by a client captures how high resolution drawings were used to discuss potential options with clients and help them visualize specific details so that they could make decisions. This was extremely important due to the client’s limited understanding of technical 2D drawings and inability to visualize the details they were approving:

Thanks Gary. I spoke with Nathan [another GlobalArch architect] yesterday and he is working on renderings to show this new direction. Until we have a visual of what the new direction will look like for my team to sign off on, we can’t officially approve the matte black finish.

	Low Resolution	High Resolution
Conceptual (with clients)	<ul style="list-style-type: none"> • Agree on mutually acceptable design • Reduce chance of confusing client and clarify erroneous misconceptions • Get initial feedback and commitment from client 	<ul style="list-style-type: none"> • Visually represent and communicate the project’s story and design intent • Help client envision how the final building will look • Facilitate decision making and get approval
Technical (with contributors)	<ul style="list-style-type: none"> • Provide and seek feedback from contributors • Present or resolve misinterpretations • Resolve ambiguities about revisions 	<ul style="list-style-type: none"> • Facilitate decision making and get approval of details • Communicate design intent and ensure that details are aligned with it • Minimize number of questions raised

Table 1: Summary of the architects’ intentions with conceptual and technical, low and high resolution drawings

In sum, our analysis suggests that architects used low resolution drawings with clients to communicate rough ideas and get early feedback and commitment. High resolution drawings, in contrast, were created to convey the design vision, facilitate decision making, and seek approval. Even though these high resolution drawings contributed little, if any, content to the final 2D drawings, they were instrumental in helping the architects visually communicate their ideas and facilitate decision making.

Contributors

The resolution of drawings for contributors also ranged from low to high depending on the architects’ intentions (see Table 1). Low resolution technical drawings had few details and specifications, such as dimensions, line thicknesses and symbols. Furthermore, the content and details included were often sparse and mostly estimates. Examples of low resolution drawings included technical hand sketches and 2D drawings with limited details and dimensions. High resolution drawings, in contrast, included many details and specifications, which were precise and drawn to scale. Examples of high resolution drawings created for contributors included detailed 2D AutoCAD drawings and 3D models with dimensions.

With contributors, the architects created and used low resolution drawings to provide and seek feedback, clarify misinterpretations and communicate revisions. During one observation, for example, Lisa was creating a sketch by

hand on tracing paper with a red color pencil with the intention of trying to complete the revisions and answer the questions that Phil, the structural engineer, requested “as soon as possible.” When asked how the tracing paper sketch was used in the review process, Lisa said she would show the sketch to Gary and she might even scan it and send it to Phil to “get quick thoughts on if he thinks the revisions will work.” Specifically, Lisa explained that these changes would be sent back to Phil and needed to be reviewed by him so that he “can put his engineering stamp on it before we can order steel.” Lisa added that her goal was not to make the drawings extremely detailed before she sent them to Phil because the drawings might change based on Phil’s feedback. Therefore, Lisa was adding only the necessary details that would allow Phil to approve the placement and thickness of the steel beams.

Low resolution technical drawings were also used to either prevent misinterpretations or resolve misunderstandings between the architects and contributors. Even though technical drawings were more rigid in terms of how they could be interpreted, they still had to be interpreted by contributors, which was not always easy to do. Therefore, when questions arose, the architects and contributors would create new or modify existing technical drawings to clarify potential misunderstandings. Below is an excerpt from an email sent to Gary from a structural engineer seeking feedback and requesting input to clarify his understanding of details related to the building’s foundation:

“We’ve drawn a bunch of sections to help understand the various foundation conditions at the L1 [Level 1] addition based on the DD [Design Development] set. There are still some questions we have and some dimensions to confirm. I’m sure we’ve misinterpreted a few things as well, in particular with respect to the location of the structural slab edge. Can you please review, help us fill in the blanks, and confirm or revise based on the architectural design?”

This excerpt is indicative of the situations in which low resolution drawings were used to coordinate with contributors, provide clarity and confirm details in existing technical drawings. Ultimately, low resolution drawings enabled the architects to quickly communicate with contributors and get feedback from them without having to constantly create highly detailed or complex drawings.

High resolution technical drawings, on the other hand, were often created by the architects with the intention of facilitating decision making, coordination, confirming and approving details and ensuring a reliable implementation later on. Specifically, throughout the project, contributors made a variety of important decisions related to technical details and local regulations, some of which were minor and easy to implement (e.g., moving the location of a light fixture) while others were more substantial and resource intensive (e.g., relocating the position of a fire department connection pipe). Therefore, the architects strategically produced and customized high resolution drawings to the

needs, knowledge and tasks of the contributors. For example, the excerpt below captures how high resolution drawings were used by contributors in the final project phases to prepare submittals for the materials they planned to use, which were then reviewed and approved by the architects to assure they matched the design intent:

“In construction documentation you take those concepts [from design development] and determine how they actually come together... You have to define it [referring to materials] enough so that contractors can price it... a contractor will have different ideas on means and method of achieving the design intent, but as long as the contractors suggestion does not change the design intent it does not matter if the materials the contractors choose are less expensive.”

High resolution technical drawings were also intended to facilitate communication of the design intent and ensure that details and drawings aligned with it. The architects’ design intent was often visually complex and reflected a considerable amount of tacit knowledge. Therefore, as captured in the following excerpt, high resolution drawings were a critical medium used by the architects to convey and protect their design intent and vision when working with the professional renderers:

When asked what he is looking for in the renderings when making comments, Charlie said “I am making sure the geometry they are working with is in line with the design intent... our job is to get them [the renderers] to do what we tell them. They don’t know our design intent. They need to know what example or material” they should look at when creating the renderings or else “they will use whatever they think is best.” Charlie said “we communicate with them through drawings.”

Furthermore, high resolution technical drawings helped minimize questions from contributors and prevented contributors from sending the architects “Requests for Information,” or “RFIs.” As explained in the excerpt below, providing contributors with detailed drawings throughout the project was one way to minimize the number of questions asked:

When asked what the RFIs are about, Gary says they are asking questions like, “What did you mean by this?” Lisa adds, “Which we get many of.” Gary adds, “Which is why the more detailed we are in drawings, the easier it is and less questions.”

Overall, we found that architects created low resolution drawings for contributors to get quick feedback and to verify a shared understanding of design elements or revisions with contributors before moving forward. High resolution drawings, in contrast, were used with contributors to specify, confirm and zoom in on project details, which ultimately minimized the number of questions and concerns raised by contributors.

Managing Focus of Attention

Regardless of the content and resolution reflected in the drawings, we noticed that architects also employed curation strategies with the intent of directing actors' attention to particular aspects of the project and away from others. As described in this section, different tactics were used depending on whether the drawings aimed to manage the attention of clients or contributors.

Clients

When managing the focus of attention of clients, architects provided a “few options” to choose from. In these situations, the architect's carefully curated and strategically presented drawings with the intention of finding out which ideas the client liked best while simultaneously preventing the client from selecting clashing elements that did not go well together, thus preserving the design intent. When preparing for a client meeting, for example, Robert (an architect) intentionally only developed “two more-or-less fluid concepts, where elements align, to present to the client, and see which they like best.” Robert explained that the reason for this was because the “downside to giving the client too many options for each of the concepts (like capacity, massing, etc.) is that the client gets confused or wants to combine clashing elements that they like, but don't go very well together.” Therefore, rather than providing clients with many open-ended options, drawings were intentionally curated to focus the client's attention on a handful of concepts in an attempt to limit the possible directions of the project while simultaneously receiving feedback from the client. In another example, Karl explained how the architects would provide their client with a few possible options, to which the client then responds:

When asked about the bridge, Karl says that “we” will give them a few options. He opens Rhino and clicks through different views of the towers. He zooms into an elevation view of the bridge and says, for example this one has a pool. When asked about why they want a bridge, he laughs as he says, they just say, “It would be cool if there was a bridge.” Karl adds that when he spoke with the structural engineer, he says that it could actually be more efficient, because the bridge helps hold the towers up...He pulls another image of the main tower from a pile on his desk and points out a translucent glass swirl that goes along the tower. He says that the client “thought the spiral was too trendy,” and shows how the spiral is no longer in the existing image of the tower in Rhino.

In this particular example, Karl and his team were trying to select drawings that satisfied the client's request for a bridge and removal of the “trendy” swirl that went along the tower in a prior design. By curating drawings based on what elements went well together, the architects aimed to help clients make decisions that were aligned with the agreed upon design intent and minimize requests from the client that could lead to a less desirable outcome.

Contributors

The architects also strategically selected and created drawings with the intention of managing the attention of contributors. In particular, architects managed the attention of contributors by curating and emphasizing certain details in the drawings. This helped the architects limit the scope of the project and prevent unnecessary changes while simultaneously making sure to set realistic expectations, ensure the reliability and quality of deliverables and protect the design intent and vision for the project. For these reasons, the architects made sure to only elaborate on content that was necessary for contributors to complete their tasks and limit unnecessary changes or feedback outside of the scope of the focal task.

We observed several instances in which the architects intentionally omitted particular content from drawings in attempt to prevent extra work. For example, below is an excerpt from the permitting process, in which the drawings were modified to only include the content necessary for the exterior permit set. According to Lisa, including extra content outside the scope of the review, such as the interior changes, could result in additional unnecessary changes and slow down the permit process:

Lisa said the design development documents show the plan for the exterior and interior changes, but “it is best not to show interior” when seeking an exterior permit. Lisa continued and said that if they were to include the plans for the changes to the interior when seeking an exterior permit, it is possible the city may ask questions about a change to the interior which would then slow down the process of gaining the exterior permit.

In addition to omitting particular content from the drawings, another way the architects managed the attention of contributors was by adding annotations to the drawings. The architects annotated the drawings to specify and communicate what contributors should focus on and what should be ignored. For example, during one observation, Gary added a big rectangle with a thick black dashed border around part of the drawing he was working on. When asked about the black dashed line, Gary explained that the permit reviewers should only comment on the stuff on the first floor and he “wants to show what they shouldn't comment on.” Similarly, in another observation, Gary annotated drawings by adding red text labels next to certain details using the markup tool in Adobe Reader. Specifically, Gary was attaching the drawing to an email he was sending the structural engineer and the annotations were intended to draw attention to and elaborate on the parts of the drawing that referred to the content in his email.

Given the different expertise, responsibilities and priorities of the architects and contributors, the architects often needed to negotiate with contributors to ensure that the design intent of the project was preserved. When creating drawings intended for contributors, it was clear that managing attention by annotating and omitting drawing

content was an important strategy employed by the architects. This technique enabled the architects to prevent contributors from requesting changes or providing feedback on details unrelated to the task at hand while simultaneously allowing them to highlight elements to which the contributors should pay attention.

Taken together, managing the focus of attention of clients and contributors allowed the architects to preserve the design intent by preventing incompatible changes and ideas from being proposed. By curating drawings and their content for clients and contributors, the architects strategically crafted the focus of the client and contributor's attention in attempt to further the project along and achieve the design intent and vision agreed upon with the client.

DISCUSSION

Our main finding in this paper is that drawings are strategically created depending on the intention of the creators with the specific actors for whom the drawings are intended. We identify three strategies that were frequently used by the architects at GlobalArch when creating drawings for the clients and the external contributors collaborating on the project. Employing these strategies enabled the architects to structure, support and guide decision making as well as facilitate interactions with clients and contributors in attempt to achieve the agreed upon design intent for the project. Specifically, these strategies included selecting the drawing content, which was either conceptual or technical, and the resolution of the drawing details, which ranged from low to high. The architects also employed strategies to manage the actors' focus of attention by curating which drawings and content were included and highlighted.

The strategies employed by the architects along with the many different types of drawings they created demonstrated the architects' careful thought process along with the decisions and intentions they embedded into each drawing. For example, when the goal was to prevent clients from requesting costly changes or combining clashing elements, the architects carefully managed the focus of the client's attention to certain details and options by curating the drawings to only convey a bounded set of concepts and possibilities. On the other hand, when the architect's wanted to get initial feedback from clients, they created high resolution 3D drawings or professional renders, which were highly visual and easy to interpret. It was clear, therefore, that when creating drawings, the architects carefully thought about which strategies to employ to assure the drawings helped them achieve their objective with the intended set of actors for whom the drawings were created.

The intentions and actions of the architects were not selfish acts but rather aimed at preserving the vision for the project and ensuring its success. To do this, the architects needed to communicate effectively with the different stakeholders by providing each of them with the information they needed in a way they could understand. Therefore, by carefully

crafting and curating the drawings for their intended recipients, the architects were bringing value to the project and making sure the vision was successfully achieved. Interestingly, when we discussed our findings with one of our contacts at GlobalArch, he expressed that the strategies used to create the drawings were not explicitly articulated or taught but rather implicitly learned and incorporated as a "taken for granted" aspect of the practice.

Our findings are consistent with and build on previous research that has extensively documented the important social role of drawings and the way in which they structure interactions, learning and work processes [4,7,9,14,15,21,22]. While recent work has started to suggest that drawings might, in fact, be strategically created in attempt to structure and influence some interactions [3], virtually nothing has been said about the intentions of the individuals creating the drawings and the strategies they use to craft the drawings.

Inline with previous work by Bellotti and Edwards [5], our findings illustrate that intentions are a key driver underlying the behaviors of the architects and their interactions with clients and contributors. Specifically, the strategies and practices employed by the architects enabled them to adapt the drawings to the context in which they were being used and the actors with whom the drawings were being shared. It was clear in our data that the architects thought carefully about the purpose of each drawing as it was created. In fact, crafting the drawings to achieve certain intentions was an integral part of the architect's job. By doing this, the architects were able to ensure that they were meeting the needs and expectations of their stakeholders while simultaneously working towards successfully achieving their design intent and overarching vision for the project.

Therefore, rather than viewing the social role of drawings as an emergent byproduct, these findings suggest that the social role of drawings is one of the driving forces underlying how drawings get created. Surprisingly, with the exception of Barley et al.'s [3] study, which showed that engineers purposefully made objects more ambiguous or more clear depending on their goals, most research has overlooked the design strategies used to create objects in attempt to influence the social processes they support. We extend the work of Barley et al. by documenting an even more nuanced process of manipulating drawings along with the multiple concurrent strategies used to achieve a wide range of goals.

Our analysis of the strategies employed by architects at GlobalArch also reveals that the different types of actors involved with a project are an important factor that determines how drawings are created. We describe the strategies used to create objects intended for individuals outside of the organization who in some cases use the drawings to contribute technical knowledge and expertise to the project (i.e. the contributors) and in other cases have virtually no technical knowledge but use the objects to

request changes and make decisions (i.e. the clients). Specifically, these findings suggest that while the intentions of the architects with both the clients and contributors were often similar, achieving them required different drawings and strategies due to the recipients' distinct needs, expectations and knowledge. We therefore build on the work of Barley et al. [3] by demonstrating that workers not only create drawings with specific intentions, but also that drawings and how they are curated vary significantly depending on the audience.

Design Implications

These findings have important implications and raise interesting questions for designing knowledge management systems, collaboration platforms and software used for highly visual and technical work. Below we identify and discuss three opportunities for better supporting work environments that involve many types of drawings. In particular, we discuss the need to easily customize and curate drawings for different audiences, the need to share drawings more easily, and the need to preserve drawings electronically.

First, we observed that architects duplicated effort by generating similar drawings for different audiences. The architects also spent time curating sets of drawings to accommodate the needs and capabilities of these different recipients. We believe there is an opportunity and need for context-aware applications to take into account the context of the architect, e.g. the intended recipient of a drawing, the phase of the design, etc. As argued by Bellotti and Edwards [5], however, systems cannot rely solely on context awareness and it is important for them to make visible to users the basis of their inferences, as well as involve users and provide them with the information they need to make the system work for them. For example, a context aware system for architects could suggest drawings that are relevant depending on the person with whom they are being shared as well as the particular event or situation for which they are created, but leave the final decision up to the architects because of their superior knowledge about a given set of actors.

By making visible what the system already knows about the specific actors, event and project, this kind of system could provide architects with guidance while still allowing them to maintain control of the situation and make decisions based on their intent. For example, architects could create or augment user profiles for clients and contributors and then hide certain details and annotate other details depending on which profile is activated. Profiles could also be created for different purposes, such as the exterior permit drawings, which only require details related to the building's exterior, thus saving creators a great deal of time. Bellotti and Edwards [5] also caution that context-aware systems should ensure user accountability, such as enforcing the disclosure of who has made what changes. This becomes crucial in a setting like GlobalArch in which

multiple architects are modifying and/or relying on the same drawings and these drawings are continually modified throughout a project.

Our findings also highlight the need for applications, such as AutoCAD and Rhino, to better integrate and allow for drawings and artifacts to be created and maintained across multiple programs. Oftentimes, users of these programs, such as architects, use a variety of applications, artifacts and tools in attempt to meet their needs to share customized drawings with stakeholders across many different organizational and professional boundaries [12,28]. To overcome these challenges, new features and applications are needed to organize and maintain drawings created in different applications. For example, if a drawing has been created in both AutoCAD and Rhino, making a change to a drawing in one program could either automatically make that change to the drawing in the other program or at least notify the user of the dependency.

Second, the architects we observed struggled to share the drawings that they created across the organizational boundary. During our observations, the persistent need to communicate and collaborate with actors across diverse boundaries introduced extra work and coordination challenges for the architects since they were constantly switching between applications, such as AutoCAD and Rhino while simultaneously creating, sharing and incorporating other types of drawings, such as hand sketches and professional renders. Overcoming these challenges, however, was critical in order to create drawings that met the needs, expectations and goals of the actors as well as the specific intentions of the architects.

Cross-boundary work that is highly visual, like architecture and engineering, would benefit from knowledge management systems that better support sharing artifacts with individuals outside of the organization. Rather than having users share materials via email, which is typically what we observed at GlobalArch, by facilitating sharing and communication across organizational boundaries, knowledge management systems can enable more rapid sharing. For example, architects could share documents directly through the knowledge management system, similar to what cloud file sharing and collaboration systems, such as Dropbox and InVision, currently do. This could then make it easier for the knowledge management system to support all of the interactions between the architects and the clients. These interactions between the architect and client could then also be visible to other team members involved with the project and get saved in the knowledge management system for future reference.

Finally, we saw a need for drawings to be preserved for later reference. Most knowledge management systems tend to be very text heavy, which makes it difficult to effectively support highly technical or visual work, such as architecture. Furthermore, many of these systems require

extensive effort by the user to upload information and artifacts. As captured in one of our observations of Grant:

Grant switches to another Rhino drawing where he describes working on “texture maps for panels.” Grant comments, “I hate making them [texture maps for panels].” Grant expanded, “they are arduous to make from scratch...you would think that we have copies” of texture maps from previous projects that can be used, but “they are hard to find.”

We argue that context aware systems are needed that make it easy to document, search and share visual artifacts, such as drawings. Such a system should ensure that drawings become easily searchable and reusable. Furthermore, this kind of system would prevent the need for duplicating drawings every time they are customized or shared by dynamically pulling relevant and up to date content from a centralized repository. This type of system would make it easy to curate drawings for different actors or events and simultaneously keep track of which drawings were sent to which individual at which phase. For example, the system might automatically extract metadata and components from the drawings and supplement that data with information about who the drawings were created for and the intended purpose. This would make it easier to search for similar documents and information across projects while simultaneously reducing the burden of manually uploading information to the system. These systems could also automatically backup and preserve each version of the drawing and make it easy to search and retrieve different versions depending on the criteria of the individual searching.

Given that the effectiveness of knowledge management systems relies on their ability to align with existing work habits and processes [2,30], better systems are needed to support knowledge management and coordination for work that relies on drawings and artifacts. In these environments, the demands, constraints and strategies are malleable and constantly changing [23]. Furthermore, since the final set of 2D drawings delivered to the client at the end of the project only reflected a fraction of the total work that went into creating them, much of the work and knowledge embedded in drawings remained invisible. When work is invisible and constantly changing, it becomes difficult to support and coordinate [23,26] due to the complex and unpredictable tasks and interdependencies. Therefore, while 3D and other types of drawings helped structure social interactions and in some cases even pursue a hidden agenda, much of the extra time and effort spent on these drawings went unnoticed, was uncompensated for and did not get preserved in the organization’s knowledge management system.

CONCLUSION

Drawings are at the core of many creative and technical professions, such as architecture, design and engineering. As demonstrated in this paper, drawings are not only essential to design and construct a building but they are also

fundamental to the way architects structure and craft their interactions with different stakeholders. By illustrating the important social role drawings played at GlobalArch and the design strategies architects employed to achieve specific intentions, this study contributes a more nuanced understanding of the underlying intentions that drive how drawings get created and used with different sets of actors. Ultimately, a clearer understanding of the intentions embedded in objects as well as the ways in which objects are created and used will enable scholars to fill important theoretical gaps in the boundary objects literature and develop more effective technologies to support work that is centered around objects, such as drawings.

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REFERENCES

1. Mark Ackerman. 2000. The Intellectual Challenge of CSCW: The Gap Between Social Requirements and Technical Feasibility. *Human–Computer Interaction* 15, 2, 179–203. http://doi.org/10.1207/S15327051HCI1523_5
2. Maryam Alavi and Dorothy E Leidner. 2001. Review: Knowledge Management and Knowledge Management Systems: Conceptual Foundations and Research Issues. *MIS quarterly* 25, 1, 107–136. <http://doi.org/10.2307/3250961>
3. William C Barley, Paul M Leonardi, and Diane E Bailey. 2012. Engineering Objects for Collaboration: Strategies of Ambiguity and Clarity at Knowledge Boundaries. *Human Communication Research* 38, 3, 280–308. <http://doi.org/10.1111/j.1468-2958.2012.01430.x>
4. Beth A Bechky. 2003. Object Lessons: Workplace Artifacts as Representations of Occupational Jurisdiction. *American Journal of Sociology* 109, 3, 720–752. <http://doi.org/10.1086/379527>
5. Victoria Bellotti and Keith Edwards. 2001. Intelligibility and Accountability: Human Considerations in Context-Aware Systems. *Human–Computer Interaction* 16, 2, 193–212. http://doi.org/10.1207/S15327051HCI16234_05
6. Jean-François Boujut and Eric Blanco. 2003. Intermediary Objects as a Means to Foster Co-operation in Engineering Design. *Computer Supported Cooperative Work (CSCW)* 12, 2, 205–219. <http://doi.org/10.1023/A:1023980212097>
7. Paul R Carlile. 2002. A pragmatic view of knowledge and boundaries: Boundary objects in new product

- development. *Organization Science* 13, 4, 442–455. <http://doi.org/10.1287/orsc.13.4.442.2953>
8. Paul R Carlile. 2004. Transferring, Translating, and Transforming: An Integrative Framework for Managing Knowledge Across Boundaries. *Organization Science* 15, 5, 555–568. <http://doi.org/10.1287/orsc.1040.0094>
 9. Lars Rune Christensen. 2013. *Coordinative Practices in the Building Process: An Ethnographic Perspective*. Springer. <http://doi.org/10.1007/978-1-4471-4117-4>
 10. Juliet Corbin and Anselm Strauss. 2008. *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*. Sage Publications.
 11. Ellen Y Do, Mark D Gross, Bennett Neiman, and Craig Zimring. 2000. Intentions in and relations among design drawings. *Design Studies* 21, 5, 483–503. [http://doi.org/10.1016/S0142-694X\(00\)00020-X](http://doi.org/10.1016/S0142-694X(00)00020-X)
 12. Brent Gallupe. 2001. Knowledge management systems: surveying the landscape. *International Journal of Management Reviews* 3, 1, 61–77. <http://doi.org/10.1111/1468-2370.00054>
 13. Barney G Glaser and Anselm L Strauss. 1967. *The Discovery of Grounded Theory: Strategies for Qualitative Research*. Aldine Publishing Company.
 14. Kathryn Henderson. 1991. Flexible Sketches and Inflexible Data Bases: Visual Communication, Conscription Devices, and Boundary Objects in Design Engineering. *Science, Technology & Human Values* 16, 4, 448–473. <http://doi.org/10.1177/016224399101600402>
 15. Kathryn Henderson. 1998. The role of material objects in the design process: A comparison of two design cultures and how they contend with automation. *Science Technology Human Values* 23, 2, 139–174. <http://doi.org/10.1177/016224399802300201>
 16. Charlotte P Lee. 2007. Boundary Negotiating Artifacts: Unbinding the Routine of Boundary Objects and Embracing Chaos in Collaborative Work. *Computer Supported Cooperative Work (CSCW)* 16, 3, 307–339. <http://doi.org/10.1007/s10606-007-9044-5>
 17. Wayne G Lutters and Mark S Ackerman. 2006. Beyond Boundary Objects: Collaborative Reuse in Aircraft Technical Support. *Computer Supported Cooperative Work (CSCW)* 16, 3, 341–372. <http://doi.org/10.1007/s10606-006-9036-x>
 18. David Martin. 2012. The cooperative use of material resources and contextual features in graphic design work. *Design Studies* 33, 6, 589–610. <http://doi.org/10.1016/j.destud.2012.06.007>
 19. Gina Neff, Brittany Fiore-Silfvast, and Carrie Sturts Dossick. 2010. A Case Study of the Failure of Digital Communication to Cross Knowledge Boundaries in Virtual Construction. *Information, Communication & Society* 13, 4, 556–573. <http://doi.org/10.1080/13691181003645970>
 20. Davide Nicolini, Jeanne Mengis, and Jacky Swan. 2012. Understanding the Role of Objects in Cross-Disciplinary Collaboration. *Organization Science* 23, 3, 612–629. <http://doi.org/10.1287/orsc.1110.0664>
 21. Andreas F Phelps and Madhu Reddy. 2009. The influence of boundary objects on group collaboration in construction project teams. <http://doi.org/10.1145/1531674.1531693>
 22. Wolff- Michael Roth. 1994. Thinking with Hands, Eyes, and Signs: MultiModal Science Talk in a Grade 6/7 Unit on Simple Machines. *Interactive Learning Environments* 4, 2, 170–187. <http://doi.org/10.1080/1049482940040204>
 23. Kjeld Schmidt and Carla Simone. 1996. Coordination Mechanisms: Towards a Conceptual Foundation of CSCW Systems Design. *Computer Supported Cooperative Work (CSCW)* 5, 2-3, 155–200. <http://doi.org/10.1007/BF00133655>
 24. Kjeld Schmidt and Ina Wagner. 2004. Ordering Systems: Coordinative Practices and Artifacts in Architectural Design and Planning. *Computer Supported Cooperative Work (CSCW)* 13, 5-6, 349–408. <http://doi.org/10.1007/s10606-004-5059-3>
 25. Susan Leigh Star and James R Griesemer. 1989. Institutional Ecology, 'Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. *Social Studies of Science* 19, 3, 387–420. <http://doi.org/10.1177/030631289019003001>
 26. Susan Leigh Star and Anselm Strauss. 1999. Layers of Silence, Arenas of Voice: The Ecology of Visible and Invisible Work. *Computer Supported Cooperative Work* 8, 9–30. <http://doi.org/10.1023/A:1008651105359>
 27. Susan Leigh Star. 2010. This is Not a Boundary Object: Reflections on the Origin of a Concept. *Science, Technology & Human Values* 35, 5, 601–617. <http://doi.org/10.1177/0162243910377624>
 28. Antony Tang, A Tang, Muhammad Ali Babar, et al. 2006. A survey of architecture design rationale. *Journal of Systems and Software* 79, 12, 1792–1804. <http://doi.org/10.1016/j.jss.2006.04.029>
 29. Dhaval Vyas, Dirk Heylen, and Anton Nijholt. 2009. Collaborative Practices that Support Creativity in Design. *ECSCW 2009*, 151–170. http://doi.org/10.1007/978-1-84882-854-4_9
 30. Sheng Wang, Sheng Wang, Raymond A Noe, and Raymond A Noe. 2010. Knowledge sharing: A review and directions for future research. *Human Resource Management Review* 20, 2, 115–131. <http://doi.org/10.1016/j.hrmr.2009.10.001>