MANAGING MEDIA TO MANAGE CONSTRUCTION PROJECTS

By

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To my family

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Performance failures can have disastrous consequences and occur when drawings do not convey design specifics or design intent to the project team. This study examines the means of communication linking design and execution, with emphasis on the strengths and weakness of various methods, and suggests, through case history, a path toward improved communications.

This study introduces the concept of mode of representation and how it can bring about or prevent failure, uses communication theory to describe the importance of media in delivering information, and presents Superstructures Engineers and Architects as a case study of a company designing strategies around its own performance requirements rather than allowing technology to dictate its mode of representation. In this study *mode of representation* is used to mean the format of a given document or the larger system employed for communicating; a drawing is a mode of representation, as is a CAD file. In this study *media* and *medium* refer to the vessel of delivery; paper is a medium as is a conversation. This study assumes that there are no neutral vessels and that, therefore, choice of media actively affects the way that information in drawings is organized and the way that it is perceived. A list of traits inherent to construction document media is created in this study and reviewed for relevance in construction literature and the case study.

Superstructures Engineers and Architects was chosen for study based on their pro-technology attitude towards project management and their unique system of document creation and delivery. Superstructures created a proprietary software system after analyzing their company's needs and the traits required of their documents. Their system avoids the two main causes of media-specific performance failure: miscommunication and inappropriate cost cutting. Their system is comprehensive, unified, and promotes precise, consistent interpretations of documents. It produces drawings and related documents that are easier for all project participants to grasp because of their incorporation of details and photographs. It reduces the number of times each piece of information is handled by allowing for data input in the field. It is based on a database, and so changes are incorporated across the entire document from a single point of entry. It also allows for customizable presentations of information, providing users with documents tailored to their needs and understandings.

The review of literature and the case study demonstrate that drawing media is an area of concern among construction professionals and that it is possible to manage media to reduce performance failures and to better manage project outcomes through better data management, ease of data input, and presentation of detail easily understood by all project participants. Media affects the content and the interpretation of construction documents. Rather than allowing advances in technology to dictate the format of construction drawings, it is important to study the goals of design and performance, addressing the inherent characteristics of drawings, and to use them as guiding principles for developing new technology and new communications strategies.

CHAPTER 1
INTRODUCTION

Introduction to Performance Failure

Ignore design error as a source of failure during a building project. Construction's counterpart to design failure is performance failure. Both types of failure occur in building projects and when they occur in conjunction with each other, the results can be disastrous. This thesis will ignore design failure and focus on performance failures, the failures that occur between intent, communication, and execution. It will examine the means of communication linking design and execution, with emphasis on the strengths and weakness of various methods, and it will suggest, through case history, a path toward improved communications.

Modern drawings are the culmination of the available ideas and technologies of the past, and so drawing media or modes of representation are more reflective of the state of technology than the needs of the users. This problem reflects a general industry-wide tendency to stagnate, avoid change, and economize at the expense of improvements. Drawing media have their own inherent characteristics. For example, paper is an extremely versatile and flexible tool for visualization of design, but cumbersome to revise and distribute. Performance failures can occur when drawings do not convey design specifics or design intent between the project team members. Drawings must therefore promote and facilitate collaboration while maintaining clear assignment of responsibilities. This thesis will introduce as a case study, a company that actively shapes its media usage based on performance needs rather than merely working with available technology.

In ignoring design error as a source of failure during construction, this thesis will introduce mode of representation and how it can bring about or prevent failure; use communication literature to describe the theory behind the importance of media in delivering information; and provide a case study with examples of a company designing strategies around its own performance requirements rather than allowing technology to dictate its mode of representation. *Mode of representation* will be used to mean the format of a given document or the larger system employed for communicating; a drawing is a mode of representation, as is a CAD file. *Media* and *medium* will refer to the vessel of delivery; paper is a medium as is a conversation.

Performance Failures: Hyatt Regency Case

More often than not, performance failures merely inconvenience construction. However, some failures have catastrophic results. In July of 1981 the newly opened Hyatt Regency in Kansas City, Missouri experienced such a failure when two hanging walkways collapsed during a crowded dance, killing and injuring hundreds of people. The parties involved included Jack D. Gillum and Associates, the structural engineers, Havens Steel Co., the steel subcontractor, Duncan Architects Inc., the architect, and Hyatt Hotels Corp., the owner. (Consentino 2006).

The two walkways were comprised of corrugated steel decks covered by 3 ¼- in concrete and a concrete topping. They were supported on each side by four spans of 30-ft, 16-in beams connected by steel angles, creating a 120-ft span across the atrium. The ends of each beam were supported by transverse box beams, each consisting of two butt-welded 8-inch channels. (Levy and Salavori 1992). The following excerpt provides a detailed description of the walkway supports and touches on the breaks in the chain of communication that occurred prior to the walkways' collapse:

> In the original working drawings (the last engineering drawings submitted to the contractor and the architects by the design engineers) each box beam had single holes at both ends of the flanges, through each of which was threaded a single 1-1/4-in steel rod that served as a hanger for both the second- and fourth-floor walkways. In this design the load of both walkways was supported every thirty feet by means of nuts screwed into a single rod on each side of the walkways at the level of the second-floor and the fourth-floor box beams. Thus the single rods from the steel trusses of the atrium's roof supported the weights of both walkways, but the box beams of each walkway supported only the loads on that single walkway.

In the shop drawings (the final drawings submitted to the contractor to the design engineers and the architects) each end of the fourth-floor box beams had two holes through both flanges, one at 2 in. from the end and the other at 6 in. from the end. Two upper hangers, ending at the fourth-floor level and consisting of 1 ¼ in. rods, went through the outer hole in each box beam of the fourth-floor and supported the fourth-floor walkway only by means of nuts and washers at their lower end – i.e., below the box beams of the fourth-floor walkway. Two separate lower rod hangers, starting at the fourth-floor level, went though the inner hole of each fourth-floor box beam, supported by a nut and washer at their upper ends – i.e., above the fourth floor box beam – and supported at their lower ends the second-floor walkway. This design was a change suggested by the contractor in their shop drawings and stamped "Approved" by the architects and "Reviewed" by the structural engineers…In the final contractor's design the loads of both walkways was transmitted to the roof trusses by the shorter upper rods, which passed through only the fourth-floor box beams and supported the second-floor walkway by two additional shorter rods hanging from the fourth-floor box beams. Thus in this design the fourth floor transverse box beams supported the loads of two walkways, rather than the one of the original design. (Levy and Salavori 1992).

Figures 1-1 and 1-2 show the hanger details as they were designed and then as built, respectively.

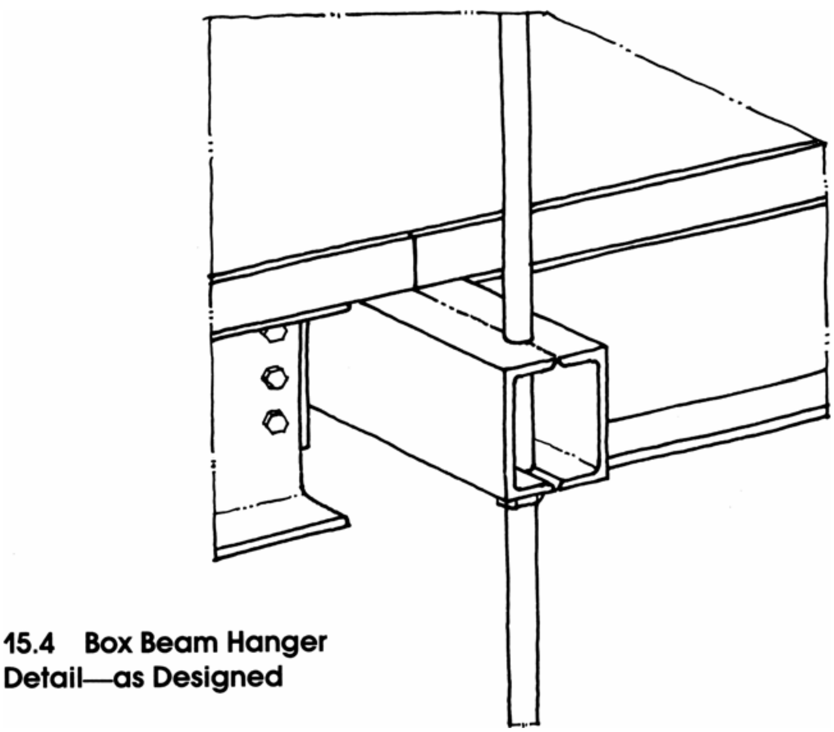

Figure 1-1. Box beam hanger as designed. (Source: Levy, Matthys and Salavori, Mario. (1992): *Why Buildings Fall Down*, W. W. Norton & Company, New York).

As detailed in Figure 1-1, the rod runs through the welded box beam, providing continuous support from the roof all the way down to the lower walkway. Figure 1-2 shows the rod fabricated in two pieces to improve buildability. One section of the steel rod hangs the fourth floor walkway from the ceiling while the second section hangs the lower walkway from the fourth floor box beams. This critical design change was presented to the engineers by the steel fabricators in the form of a shop drawing. The shop drawings were approved and the walkways were constructed as shown in Figure 1-2.

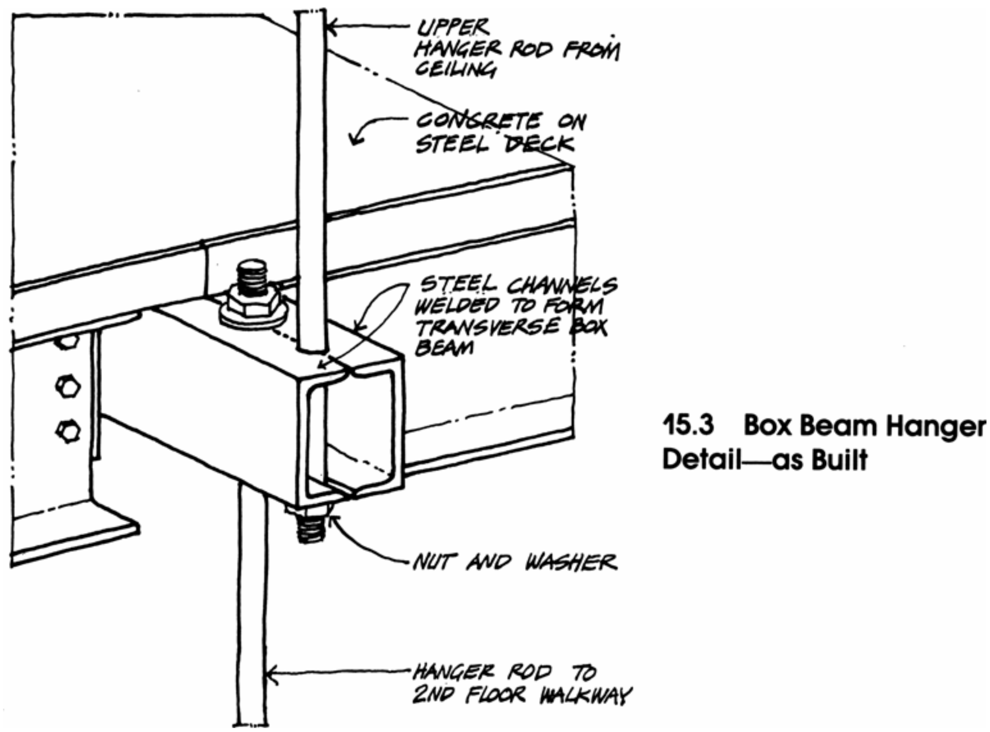

Figure 1-2. Box beam hanger as built. (Source: Levy, Matthys and Salavori, Mario. (1992): *Why Buildings Fall Down,* W. W. Norton & Company, New York).

Post-collapse analysis proved that there were design failures beyond the design changes unnoticed by the structural engineers. For example, the design calculations for dead load were 8% lower than the actual dead load because the concrete topping over the steel decking was not shown in the drawings, only required by the specifications. (Levy and Salavori 1992). Additional oversights or miscalculations on the design end will not be discussed as they are irrelevant to this study. Relevant analysis relates to the failures that occurred in communicating design intent for execution. The Kansas City Star reported that Havens Steel Co. president, Fred Havens, said, “It appeared that the walkways were made for light traffic,” whereas Hyatt president Pat Foley said that the skywalks “were designed to hold people shoulder to shoulder, as many as you can jam on there.” (Consentino 2006). This case proved to be a fatal union between design error and performance failure.

Analysis: Hyatt Regency

The performance failures in the Hyatt Regency case can be linked to many professional failures, including miscommunication or failure to communicate, professional negligence on the part of the designers and builders, ignorance of state codes, scheduling constraints, and financial constraints. It is not in the scope of this thesis to examine every angle of a performance failure, but to isolate the areas related to mode of representation. In this case, fault can be found with the design drawings and the shop drawing review process. Fischer et al. (2002) agree that “the major opportunity for improving the design and construction of facilities lies at the interface between the disciplines.” When not just improved design and construction are at stake, but hundreds of lives and hundreds of millions of dollars in damages and legal expenses, that point is very well taken. Figure 1-3 shows the aftermath of the collapse.

Figure 1-3. Aftermath of collapse. (Source: Lowery, L. (2007): Aftermath of Collapse. Retrieved October 15, 2007, from http://ethics.tamu.edu/ethics/hyatt/hyatt2.htm).

Analyzing the Kansas City Hyatt Regency case from the perspective of mode of representation, we can break down the performance failure into two parts:

- Organization of ideas (input-side)
- Delivery (output-side).

Organization addresses the idea that mode of representation determines the way we organize our ideas and select information to be conveyed. Organization defines the way that document creators work with information. *Delivery* addresses the idea that mode of representation influences the interpretation of that information. Delivery defines the way that document users perceive information. Mode of representation and media are more than just passive means of transmitting information – their inherent characteristics actively affect our understanding. The Hyatt example demonstrates that a construction project's chain of communication can have a powerful impact on the project's outcome. Now we will examine the role that mode of representation and media play in that chain of communication.

In the case of the Hyatt, the chain of communication was broken in two major places: the designers failed to convey the specifics of their intent to the builders, and the builders failed to communicate the specifics of their changes to the designers. The result was no mutual understanding of the importance of a simple detail. Figure 1-4 shows the cycle of presentation and review of drawings where communication failed in the Hyatt Regency case.

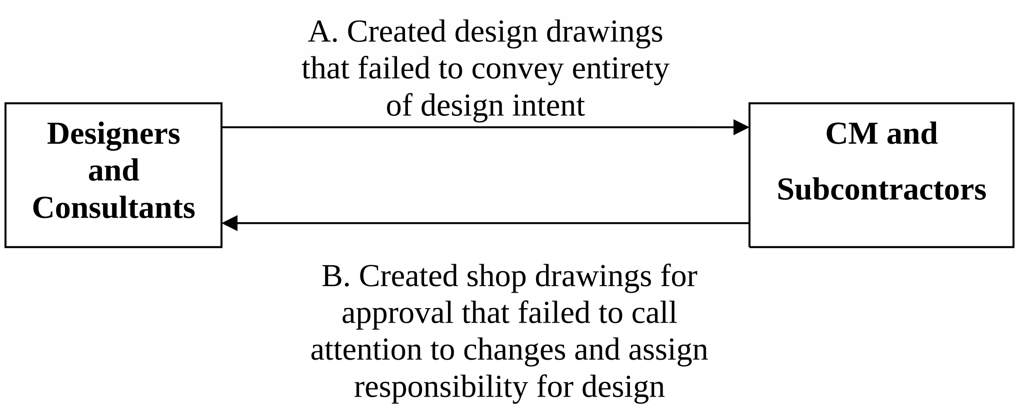

Figure 1-4: Communications breakdown in the review process of the Kansas City Hyatt Regency

Portion A relates to the failure of the design drawings. Input was provided by the engineer and architect and the output was interpreted by the contractors. Portion B relates to the failure of the shop drawings. Input was provided by the contractors, which was then interpreted by the engineer and architect. As a mode of representation, these documents failed at the input side as well as the output side.

The Hyatt case demonstrates the combined performance failures of human error and document error. Human error is difficult to predict or combat, but failures that result from ineffective documents are inexcusable. The Hyatt collapse precipitated changes in building codes, in engineering practices, practices regarding the review and approval of drawings, and in the assignment of responsibility for shop drawings. It should also be used as a platform to begin examining the need to change the documentation systems themselves, and is the starting point of this thesis.

Introduction to Media Limitations

The above case study gives an extreme example of the kind of problems that media-related miscommunication can cause on a construction project. Every drawing format or communication tool, from a napkin to a 4D model, has certain inherent characteristics that limit the type of information conveyed, the manner in which it can be conveyed, the level of detail to which it is portrayed, and the audience to whom it is appropriate. Wanda Orlikowski (2000) wrote,

> Human agents build into technology certain interpretive schemes (rules reflecting knowledge of the work being automated), certain facilities (resources to accomplish that work), and certain norms (rules that define the organizationally sanctioned way of executing that work).

Orlikowski agrees that every technology or mode of transmitting information has its own inherent characteristics. For example, plans on paper cannot easily show sequence of operations, 3D CAD drawings do not necessarily reflect the current understanding of building tradesmen, and oral communications lack the formal reproducibility of written transmission. Each mode of representation has rules of use and limitations on content that affect how and what information is presented. Each medium colors the information that it contains. Ong refers to this idea as the *communication bias* of a medium (Gladney 1991) and Pérez-Gomez and Pelletier (2000) say that it is *critical* that we "acknowledge that value-laden tools of representation underlie the conception and realization of architecture." No matter how this premise is described, drawing media affects both the creators of the drawing and the end users who read the finished product. Media affects both input and output of information and it will either help or hinder designers and builders in conveying their design and building specifics.

In the passage below Fischer (2004) illustrates the problems associated with technology-driven modes of representation that do not respond to the needs of their users. Without a common vision of the project, ambiguities and miscommunications are rampant. Without properly tailoring their information systems to their operations, designers and builders waste resources implementing technology. This technology dilemma is outlined in the form of a project planning meeting:

> For most decisions about a project, engineers from different disciplines…(a designer, project manager, cost estimator, scheduler, and MEP coordinator) need to share their information with others on the project team…In this meeting, each engineer formed an image of the current status of the project and visions of future situations in his head based on his own interpretations of the documents from the other engineers. These interpretations formed the basis for discussions and decisions about the most appropriate design of the facility and its parts, when, how, and by whom it should be built, how long the whole project or a part of the project should take, how much things will cost, etc. In this way, a large portion of the planning and coordination of the project occurred primarily in the engineers' heads and was not supported by IT. In our experiences, this use of IT is typical on projects. Because decisions are mostly based on personal and human interpretations of information generated by many engineers from many disciplines the decision process and resulting actions and results are not consistent and repeatable from meeting to meeting and project to project. As a result it is difficult to predict the outcome of the current design and construction process, and IT contributes little to predict the outcome of projects reliably. (Fischer 2004).

Predictability and repeatability of interpretation are the desirable outcomes of proper communication. When design intent is clearly communicated for execution, these should be the results every time and media-related performance failures should be zero. Additionally, Fischer's claims can be extended to suggest that if project outcomes could be predicted more reliably, project resources could be more efficiently managed, and so gains could be made. From the perspective of mode of representation, what can be done about this? One solution is to look outside the boundaries of conventional construction wisdom. Incorporating the understanding of other disciplines may help to unravel the problems in construction media. Communications theory will be explored to help identify problem patterns in dealing with construction drawings.

Improving the way designers and builders understand drawing media can help improve technology's contribution to construction projects. This thesis will investigate communications theory to help identify areas of concern in construction drawing media. Heyer defines *communications* and *communications media* as, "The social interaction role of language and speech, various systems of writing, and any subsequent technology used to organize information and impart knowledge." (Heyer 1988). This definition is important to the scope of this thesis because it describes communications media as organizing and imparting knowledge. For the purpose of this thesis, construction drawing media will be considered to play an *active* role in the organization and delivery, the creation and interpretation, of content on a project. Two communications theorists will be introduced to support this assertion and their theories will be examined against a construction case study to verify their relevance to reducing future performance failures. Isolating one possible area for improvement could help prevent disasters similar to the Hyatt collapse, but more likely, simply reduce day-to-day inconveniences on construction projects.

Summary of Introduction

This paper focuses on construction drawing media and the importance of understanding the mode of representation to creating usable documents. We will study one company that has invested in their mode of representation and has attempted to solve some of the problems with traditional documents. Improving the way that builders use available technology in this way will provide us with the tools for maximizing benefits from future technologies.

Consider the Hyatt Regency collapse. Consider failures in Boston roadways and Louisiana levees. Consider something as mundane as a bathroom plan that is not coordinated with the plumbing fixture schedule and so the sinks do not fit into the counter tops. Now remove design error from the equation and focus on the performance error. We will focus on how mode of representation shapes the path of information between intent, communication, and execution on a project.

CHAPTER 2
INTRODUCTION TO COMMUNICATION BIAS AND COMMUNICATIONS THEORY

Introduction to Communication Bias

This study focuses on construction drawing media and the importance of what Walter Ong refers to as the *communication bias* of a medium (Gladney 1991). The concept is fundamental to this study and must be explained in detail before continuing. We must accept the premise that communication bias exists in media and therefore affects mode of representation. We cannot assume a neutral vessel. What does this mean? Medium as a vessel can be a useful metaphor for understanding the concept of communication bias. There are three questions (Figure 2-1) to ask of a vessel: what can it hold, how can you put things inside, and how do the contents look?

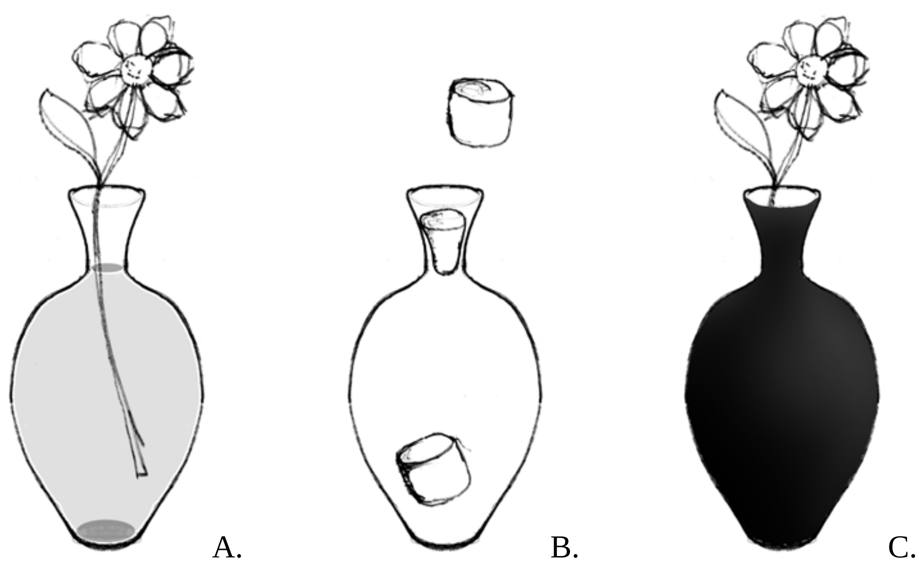

Figure 2-1: Narrow-mouthed vase: the vessel metaphor. A) Vase holding one flower. B) Marshmallows inserted into the vase. C) Opaque vase

Figure 2-1A represents the first question. What can the vessel hold? The narrow-mouthed vase can hold one flower but not five flowers. Choosing such a vase therefore determines what and how much you will be able to put inside. Figure 2-1B represents the second question. How do you put things into the vessel? If, for example, you wanted to fill your narrow-mouthed vase full of marshmallows, you would have to follow a procedure to get each marshmallow in through the top, first squeezing the air out of it. If you wanted to fill the vase with water for your flower, you would simply pour the water in through the top. The properties of the vase determine how material can be put inside. Figure 2-1C represents the third question. How do the contents of the vessel look? If your narrow-mouthed vase were opaque as shown, you wouldn't be able to tell if it were full of marshmallows or water. If the vase were translucent yellow, the contents would be visible, but take on the color yellow. If the vase were foggy or had spots, these traits would also affect the way objects looked while inside.

Simplistic though this metaphor may be, the logic is irrefutable. The properties of a medium, in this case a narrow-mouthed vase, affect what the medium can hold, how things can be put inside, and how its contents are perceived. The same logic holds for drawing media: certain properties are inherent to media and those properties affect the way information is organized and delivered.

This study uses communications theory as a way to help identify potential sources of failure in construction drawing media. The following sections introduce two men, Marshall McLuhan (1964) and Jacques Ellul (1985), whose communication theories can be applied to drawing media, supporting the argument that media plays an active role in both organizing and imparting knowledge to project participants. McLuhan's work will be described to further explain the organization, or input, side of communication bias. Organization pertains to the way that a document's creators interact with it and what and how information is added. Ellul's work deals with the delivery, or output, side of communication bias. Delivery pertains to the way a document's users interact with it and how information is perceived. Among other things, the writings of these two men demonstrate the universal nature of the media-related failures experienced on construction projects. Such problems are not unique to builders; therefore, builders should be able to gain insight by studying the works of others. The following reviews deal with these media-related failures in an effort to encourage improvements in the way that technology can be applied to construction drawing media.

McLuhan: Organization

Introduction to McLuhan

Marshall McLuhan's communications writings in the 1960s expanded the relationship seen between medium and content. McLuhan wrote that the real impact of media is the way it organizes our experiences. Meaning is not understood by studying content alone, but by looking at how media organizes our perception of content and emphasizes causal relations, order, desired specialization, and compartmentalization. He argues that a medium's message is "the change in scale or pace or pattern that it introduces to human affairs." (Gladney 1991).

From the standpoint of designing and building, McLuhan's argument can be applied to show that the inherent characteristics of drawing media limit and shape the information portrayed. Further, designers and builders who understand the inherent characteristics of media stand to use media to achieve more predictable outcomes on construction projects. Making other project team members see what you see, or at least what you want them to see, has very tangible impacts on a construction project (Fischer et al. 2002). Clear drawings and effective communication are essential to running a cost-effective construction project. (Lamendola 2004).

Different media formats will accept different kinds of information. This assertion will be reviewed below and in Chapter 3. For now, assume that there is a connection between the way designers and builders create a set of instructions and the medium of those instructions.

Organization and Media

At this point it is necessary to explain media's role in our organization of construction documents. How do media determine the way we organize information? Consider a list of inherent characteristics of media. The following organization-side media traits are among those discussed in construction reports, articles, and academic writing:

- Facilitates input
- Facilitates alterations
- Limits size and scale effectively
- Facilitates visualization
- Assigns responsibilities, reflects the chain of authority
- Promotes collaboration
- Promotes version control
- Maintains design integrity
- Responds to the level of understanding of project team members
- Allows for appropriate level of detail.

Traits such as these impact the types of information that can be included in a document. When reviewing a medium, it is appropriate to ask how the medium responds to these traits. When reviewing a company's mode of representation, as is done in Chapter 5, it is appropriate to ask which of these traits are applicable and desirable to the company's system.

Ellul: Delivery

Introduction to Ellul

Jacques Ellul's writings in the 1980s concerned the substitution of images for dialogue and meaningful discourse. Ellul (1985) argued that discourse "implies a long process: an indirect approach and a kind of winding movement involving successive approximations that irritate lazy modern people." Whereas visual representation is the "easy, efficient, quick path. It allows us to grasp a totality in a single glance, without any need to break up a thing or to analyze it." (Ellul 1985). Reducing communication to visual information in place of oral explication takes the nuance out of language, including ambiguity, variation in interpretation, and breadth of meaning.

(Ellul 1985). Can visual communication eliminate the ambiguity and varying interpretations that cause performance failures? Although Ellul was arguing against what he saw as the onslaught of visual imagery, his theories demonstrate media's importance to the delivery side, i.e. the interpretive side, of communication. This section develops the relationship between media and clarity of presentation.

From the standpoint of designing and building, media has traits that either promote or discourage variation in interpretation. Thus, designers and builders who understand the inherent characteristics of media stand to use media to achieve more predictable outcomes on construction projects. We are not trying to open a lengthy discourse when we create a set of drawings; we are trying to build something that matches the intent of the designer. A reduction in ambiguity is a desirable outcome for designers and builders and one that can be supported by manipulating the drawing media.

Ellul's ideas relate to the patterns discussed in this thesis. Ellul argues that the output of ideas, the way that people perceive information presented to them, is affected by the medium of presentation. His assertion that medium plays an *active* role in determining understanding supports an argument made by this thesis that medium can be manipulated to achieve desired outcomes on construction projects and prevent performance failures. Perceptions of information can be manipulated by changing the medium in which information is presented. This assertion is reviewed in Chapter 3. For now, assume that there is a connection between the way designers and builders perceive a set of instructions and the medium of those instructions. There are more potential choices than those described by Ellul, just between spoken word and paper, and these are described in the list of media traits below.

Delivery and Format

This section will cover some of the questions arising from Ellul's theories on communication and its power to produce and eliminate uncertainty. Does visual communication reduce the ambiguity/variation in interpretation inherent to communication? If so, some aspects of different media must work to eliminate ambiguities. Consider a list of the output-side characteristics inherent to media. The following delivery-side traits are among those discussed in construction reports, articles, and academic writing:

- Promotes ease of reading output
- Communicates scope
- Draws attention to details
- Draws attention to changes
- Saves time disseminating information
- Facilitates accuracy of reproduction
- Facilitates quick decision making
- Demonstrates documentation authority
- Facilitates reviseability
- Manages project members' expectations
- Provides universal visual presentation
- Documents process

These are examples of the kinds of traits inherent to drawing media that affect the output potential of the document. When reviewing a medium, it is appropriate to ask how the medium responds to these traits. When reviewing a company's mode of representation, as in the methodology, it is appropriate to ask which of these traits are applicable and desirable to their system. Project team members trying to reduce variation in interpretation of construction drawings and so to eliminate failures in communication consider these traits. In the future, professionals designing new technologies for creating and disseminating plan information should also consider these traits. The following sections will discuss in greater detail media types and their effects on the creation and dissemination, the input and output, of construction drawings.

Relevant Cases

Below are two additional cases that relate communication of information in a construction project to mode of representation. The first company, Office dA, mixes their use of digital and analog media based on their expertise and their needs. The second company, Kohn Pendersen Fox Architects, created a new position in their office to incorporate new forms of technology to solve the design problems that they encountered.

Company Decisions Regarding Mode of Representation

Boston-based architectural firm Office dA got its start in the early 1990s using paper drawings almost exclusively. Designs were completed almost entirely by the firm's two principals, Ponce de Leon and Tehrani. As collaboration with the rest of the team became a greater necessity and computer drafting became more common, the office began to incorporate CATIA (Computer Aided Three-dimensional Interactive Application), Rhino (Rhinoceros 3D), CAD (Computer-Aided Drafting), and other software. The principals could conceptualize and draft by hand, turning over the concept to the team to work over details digitally. Tehrani described a need to provide the team with "an intellectual set of problems" rather than something to emulate and repeat. Tehrani said, "Our drawings become didactic instruments, not only for building, but also for conceptualizing a project. We establish a relationship between drawing as a practice, geometry as a medium, and fabrication as its goal." (Broome 2007). Thus, Office dA capitalizes on the paper mode of representation for familiarity and flexibility of conceptualization while simultaneously exploiting digital modes of representation for ease of trial and error and reproducibility. The transfer between the two media can be considered the point of engagement for the team, when the design is seen as a set of problems to be solved.

Company Strategy to Implement Technology

New York and London-based architectural firm Kohn Pendersen Fox, or KPF, was faced with a problem specific but not limited to design firms focusing on facades and curtain wall design as the major design element of a building: how to build shapes that have not been built before. Their response to this problem was to create a new position at their New York office for a technology specialist who works independently with the other project teams. This person was dubbed the *Design Technology Researcher* and it became his specific task to answer questions on how to make unique shapes buildable and how to communicate the design to the engineers and builders. Steinfeld (2007) described the majority of the work as *post-rational*, meaning that the researcher was given a shape that was already designed and asked to help evaluate it for buildability. This differs from *pre-rational* analysis, which entails designing around knowable forms, such as how much curve can be manufactured into glass or how far a material can be stretched without supports. Their post-rational analyses usually involved incorporating different types of design software or creating programs to evaluate designs. Steinfeld (2007) described the goal of the position as “formalizing true representation from project conceptualization to the creation of construction and documentation drawings.” This was accomplished through the office of the Design Technology Researcher largely by manipulating the systems used create and present the designs.

CHAPTER 3
MEDIA REVIEW

Issa, et al. (2003) refer to seven common types of data for visualization: 1D, 2D, 3D,nD, temporal, hierarchal, and networks. These are modes of representation for construction. In a basic sense, the more sophisticated a format is, the more types of data it can incorporate. However, a system's inherent potential depends on more than just the types of data it can portray. As discussed previously, there are many inherent traits that affect a system's organization and delivery of information, and consequently, its effectiveness. The following traits are relevant to construction documents:

- Facilitates input
- Facilitates alterations
- Limits size and scale
- Facilitates visualization
- Assigns responsibilities, reflects the chain of authority
- Promotes collaboration
- Promotes version control
- Maintains design integrity
- Responds to the level of understanding of project team members
- Allows for appropriate level of detail
- Promotes ease of reading output
- Communicates scope
- Draws attention to details
- Draws attention to changes
- Saves time disseminating information
- Facilitates accuracy of reproduction
- Facilitates quick decision making
- Demonstrates documentation authority
- Facilitates reviseability
- Manages project members' expectations
- Provides universal visual presentation
- Documents process

The above list shows the inherent traits of both the input and output sides of drawing creation. Some of these and traits will be described in detail below, showing the way that media limits information as it is collected in the drawing and perceived by its users. The traits will be linked back to publications concerned with communication, construction drawings, and media constraints. The requirement of initial investment of time and money will also be described as this trait is relevant to the case study in Chapter 4.

Facilitates Input

Ease of input seems like an obvious trait to mention, but it is nevertheless worth observing how it can affect the type of information seen in construction drawings. The actual ease of input for different media will vary based on the areas of expertise of the project team. Fischer et al. (2002) report that 3D modeling can reduce the number of review sessions required to ensure a properly detailed design. "The availability of information and people were the major constraints for this process; building the model was very quick." (Fisher 2002). Despite the increasing ease of information input into digital formats, this is still the primary reason cited for continued use of paper media.

Facilitates Alteration

Lamendola and Lamendola (1998) were writing specifically about mechanical drawings when they described the revision process, but their assertions are relevant to all types of construction drawings. They wrote, "The drawing is a perfect place to save time and money. Changing your plans electronically or on paper is cheaper and faster than doing reconstruction; plus the end result looks like a designed project instead of a patch job." (Lamendola and Lamendola 1998). Some media allow for changes more easily than others. Digital drafting requires a greater up-front commitment of time than does paper drafting, but the revision process is much less time-consuming. Everyone benefits from developing and using media that inherently reduce revision time.

Limits Size and Scale

Information included in drawings is limited by the size and dimensions available to the medium used. Fischer et al. (2002) said, "Traditional construction planning tools, such as bar charts and network diagrams, do not represent and communicate the spatial and temporal, or 4D, aspects of construction schedules effectively." Fischer went on to suggest that 4D modeling is necessary for complex projects, projects involving multiple phases, existing buildings, cramped sites, and projects needing approval or funding. Fischer et al. described the Dillingham Construction Company and their use of 3D and 4D models in coordinating the five-year reconstruction of the San Mateo County Health Center. Over the course of the project, it became more apparent that its needs were greater than could be fulfilled with simple 1D and 2D drawings and schedule. Fischer et al. reported,

> Originally, the GC showed the construction period with a bar chart schedule based on a critical path network. As can be imagined by just looking at the "before" and "after" models, such an abstract representation of the flow and sequence of construction fails to uncover potential time-space conflicts between construction and operations. (Fischer et al. 2002).

Every project has its own requirements based on the level of complexity of the building or the schedule. As projects grow more complex, they require more flexibility of size and dimension from their construction drawings. This trait must be considered when selecting media.

Promotes Collaboration

Construction drawing media can influence the amount of collaboration between participants in a construction project. This is an important trait to consider because construction managers who can improve their ability to work with owners will be better able to predict project outcomes and so improve their profit margins.

Ordinary paper drawings are easy to pass around for discussions. They can encourage collaborative designs during the shop drawing process (Rowe 1998). 3D and 4D media can encourage collaboration by allowing the active involvement of all members of the project team. Fischer and other Stanford researchers studied the communication and media in a series of buildings including commercial structures, institutional structures, and several highly complex structures by Frank Gehry. Fischer et al. (2002) reported,

> These cases have shown that more project stakeholders can understand a construction schedule more quickly and completely with 4D visualizations than with traditional construction management tools. Since they understand the scope and schedule of a project better, the stakeholders can then provide input to the scope and schedule and the important interrelationships, and help improve the project design and schedule.

Drawings that promote understanding allow for more input from owners, users, builders, and other participants traditionally disenfranchised by the design process. Collaborating prior to the distribution of drawings short-circuits miscommunications before they have a chance to cause problems on the scale of the Hyatt disaster. Fischer et al. summarize, “Designers involved in projects that used 3D models from design through construction reported that they saw an increased coordination effort during the design phase of the project followed by fewer requests for information during construction.” (Fischer et al. 2002).

Another consideration is suggested by Stinchcombe (1990) and Sabel (1982) in their studies of manufacturing organizations. They introduce the idea of local knowledge, information that is specific to the small group of users who work with it on a daily basis. This analysis is highly relevant to construction design teams. Stinchcombe (1990) reported,

> When a large share of the information used in a given activity is such ‘local knowledge,’ a subculture grows that is more or less isolated from the rest of the organization. The subculture is organized in large measures around an information system that is of little use or interest to anyone else and so is adapted to particular concrete features of the environment, uses an arcane language or system of notation, and resists invasions by standards from larger and more uniform information systems.

Sabel (1982) referred to this as plant-specific knowledge. “Work based on such specialized and bounded information systems is quite often subcontracted for rather than built into the hierarchal plan of the main manufacturing company organization.” This plant-specific skill, as deemed by Sabel (1982), is relevant to construction as well as manufacturing because the various designers and builders involved in a construction project not only learn and use task-specific information, they jealously guard this information. Overcoming these tendencies can be an important feature of a drawing format. Does a medium encourage sharing betweens plants or does it encouraging hoarding? Does it rely heavily on symbols or notation unfamiliar to non-specialists? When media allow for the active participation of project team members, they affect the kind of information that will be included in the drawings. Drawings that can clearly explain information relevant to many project participants will encourage more active collaboration.

Responds to the Level of Understanding of Project Team Members

Certain media have a higher capacity to restrict information to the level of understanding appropriate for drawing users. A project owner will likely be less able to understand a set of electrical drawings than the electrical subcontractor who creates the shop drawings. Similarly, an engineer will require different information from a set of structural drawings than would the architect of record. Knowing this affects the kind of information that goes into the working drawings and the shop drawings. Knowing the medium’s responsiveness to these varying levels of understanding influences their creation.

Paper drawings are cumbersome to re-detail and reproduce, and therefore often contain more information than is necessary or the wrong kinds of information necessary for intended users. Digital media offer a better opportunity to filter drawing information for appropriate users. As a result, the creators of drawings can include more information initially, knowing that it will not be difficult later to filter the information.

Nigudkar and Kang (2004) wrote about the advantages of 4D modeling in building a campus model of Texas A&M University. Their findings asserted that the importance of 4D modeling is in creating a link between the spatial and temporal aspects of building. Information is stored in layers, which can be manipulated to group information in varying ways. This is useful because, while the experienced builder can visualize a building and the building process by looking at a set of 2D plans, others cannot necessarily make the same connections. Batie and Saad (2002) agreed that 4D modeling actively responds to the different levels of understanding found between project participants. They shared Nigudkar and Kang's concern for a drawing's ability to respond to the needs of it users.

> From a Construction Manager's perspective, a great design document is one that reflects an inherent knowledge of how the design will be built. It reflects the details that support the contractor's construction process. It will include sufficient information to avoid ambiguity and thereby avoid, or at least reduce, claims and disputes. (Batie and Saad 2002).

Drawing media that are responsive to the needs and understandings of its users will be more likely to be understood and, hence, more likely to eliminate communications failures caused by media misuse. This is crucial on projects where the team members with the least understanding of drawing convention have the greatest amount of input to offer to the construction process. Fischer studied the construction of a hospital where this was the case. He found that the 4D models "maximized the construction staff's understanding of the operational needs of the hospital so that the construction approach and schedule minimized the risks to the hospital operations." (Fischer et al. 2002). In this case the medium itself facilitated a higher level of understanding of both the customer's needs and the necessities of construction. The amount and level of information provided was appropriate to the audience and communications failures were reduced because of the format in which the information was presented.

Allows for Appropriate Level of Detail

A medium's potential detail capacity is its capacity for information. The scale at which information is presented determines the amount of information that can be shown. Different media has different capacity for detail and so different potential for portraying that information. To avoid communication failure, media must be considered with an eye for the detail needs of its users. This consideration directly affects the selection and input of information into construction drawings. Fischer et al. (2002) said, "Project teams need to decide what problems they want to resolve through the use of 3D and 4D models." They continue, "It is also unrealistic to expect that a group of designers and modelers has all of the expertise about construction details necessary for a detailed 3D model." (Fischer et al. 2002). At what level of detail should the model operate? If the model is supposed to operate at the level of construction detail, it must involve the builders. Draftsmen and designers are not necessarily the parties best-informed to be making construction detail decisions. Drawing detail affects the scope of information and actively determines who is involved and what details they include.

Promotes Accuracy

Certain media types have a greater potential for accuracy. Media type affects both the way that drawings are perceived and the way that they are interpreted. Lamendola and Lamendola (1998) reported,

> If the layout looks good, the plan is usually successful. This is true partly because the appearance of a drawing indicates what to expect in terms of accuracy. It's also true because the layout of the drawing will determine if people can understand and work with the content. A clear, thoughtfully laid-out drawing is conducive to a thorough and proper review before it hits the field.

Perception of accuracy is determined by the layout of the drawing. This idea is further explored by Fischer, who explained,

> The 4D model enabled the project team to produce a better set of specifications and design drawings for the construction of the project, resulting in fewer unplanned change orders, a smaller construction team, and a comfortable completion of the project ahead of schedule." (Fischer et al. 2002).

The 4D construction modeling resulted in a greater confidence in the drawings and more accurate interpretation of the instructions. These assertions confirm that media accuracy is a trait that actively affects the way drawings are perceived and interpreted.

Saves Time Disseminating Information

Despite greater up-front time investments, digital media reduces the amount of time required for distribution of drawings. This trait is affected by the medium of the drawings and it also affects the way that users perceive the information in the drawing. Drawings that can be sent quickly speed up the review and revision processes. Information that is passed quickly this way tends to be more up-to-date and accurate and so perceived with more confidence. Fischer noted that using collaborative media results in increase speed of completion, reduction in variation of interpretation, and increases the speed of re-estimation in case of design changes. (Fischer et al. 2002). All of these traits affect the confidence that project users have in construction drawings. Increasing team confidence and eliminating variation in interpretation all work to eliminate communication failures.

Requires Initial Investment of Time and Money

Lamendola and Lamendola (1998) refer to the current situation in construction drawings as an "epidemic of bad working drawings." They explained,

> A major impetus behind the deterioration in drawing quality has been cost-cutting in the name of delivering a set of drawings under a reduced fee. Anyone who's had to deal with poor documentation or poor as-built drawings knows the false economics of this approach…One useful solution to the cost reduction problem is Computer Aided Drafting (CAD). Unfortunately, many firms implemented CAD without considering traditional drafting principles or the needs of the people using the drawings. To make matters worse, they ignored the fact that CAD systems and electronic formats must follow certain principles of electronic drawing production. These principles include proper grid

> orientation and layer management, among others. This resulted in many CAD users wiping out the cost savings the software would otherwise provide them. So, not only must we contend with poor working drawings, but we also must deal with poor electronic sources of those drawings." (Lamendola and Lamendola 1998).

These assertions confirm that there are concerns regarding the initial investment of time and money into construction drawings. An effective mode of representation may require an initial up front investment of time and/or money, something which many firms are hesitant to provide. Chapter 4 will address this topic during its discussion of one particular company.

CHAPTER 4
METHODOLOGY: CASE STUDY

Introduction to Methodology

The Hyatt Regency case demonstrated that performance failures on construction projects can have catastrophic outcomes. The review of literature demonstrated that mode of representation is an area of concern among construction professionals and that it is desirable to manipulate media choice to improve communication of intent to project participants, helping to manage project outcomes. The remainder of this thesis will use this background to investigate one company's attention to media usage for use as a model for future analysis.

Proposal Method and Investigation

In order to test the hypothesis that mode of representation affects performance successes and failures, a company will be studied that uses media and technology to their advantage. Fischer and Kunz (2004) said, "We are not aware of a project that has been designed, planned, and managed with integrated product, organization, process models that relate the different levels of detail needed by the key project stakeholders across disciplines and project phases." However, for this thesis, a company has been found and chosen for study that uses this process across all of its projects. An investigation of their drawings and procedures will be conducted and interviews will be held with members of the company working in different disciplines. There is currently a lack of precedent for handling Communications theory as it applies in this way to construction documents. For this reason, a thorough investigation of one company and one set of procedures is preferable to a superficial study across many companies. The information obtained by a thorough analysis can later be applied to a broader survey of the construction industry. The following sections introduce the company being studied and their methods of project management.

Case Study: Superstructures Engineers and Architects

NYC-based exterior restoration firm, Superstructures Engineers and Architects (in future referred to as Superstructures or SEA), was chosen for study because of their special attention to the digital media used in their projects. They have a self-professed *pro-technology* attitude towards project management. Superstructures is a company of about 50 people broken into five divisions, called studios, that operate autonomously on as many as 15-20 projects at a time. Superstructures works primarily in New York's Tri-State area, but has completed design and restoration projects as far away as Nashville, Tennessee. (Iverson 2004).

SEA has set ambitious goals for implementing a new system of representation for design and documentation. Using innovative project media, SEA feels that is able to complete projects while maximizing profits and minimizing conflicts. SEA created its own unique system of project management by customizing available media and technologies to create its own proprietary software. (Golab 2004). Their commitment to using technology to streamline and automate the construction drawing process makes them an ideal candidate for study.

Process

The following process outlined demonstrates Superstructures' ideal work flow. This process has already been implemented on projects by SEA and it is their goal for long-term implementation. It will therefore be discussed as their current system, when in fact, it is not employed on every project.

When given a project by a building owner, SEA initially creates its own drawings using AutoCAD, hereafter referred to as *CAD*. They create 2D drawings for data collection and input. 3D drawings are sometimes created to demonstrate more complicated aesthetic details and for isometric details of building assemblies, but all other information is conveyed two-dimensionally through digital media. The system for collection, input, and interpretation of information employed by Superstructures is outlined below.

> During our initial building investigation we use a military-grade field laptop computer that allows us to immediately enter building data directly into the CAD drawing as we examine the building facade. To reduce the potential for human input errors, we use custom programming to provide a pre-defined drop-down list of repair conditions from which the user can choose. From there, the user can enter approximately how much (in a given units measurement) repair is needed, associate any number of photos that may be required, as well as enter any appropriate notes or comments. All of this information is entered into the CAD drawing at the time of investigation so there is little worry of having to transcribe data later. (Iverson 2004).

Figure 4-1 shows a sample reproduction of an SEA CAD drawing elevation. The building is a typical New York mixed-use building.

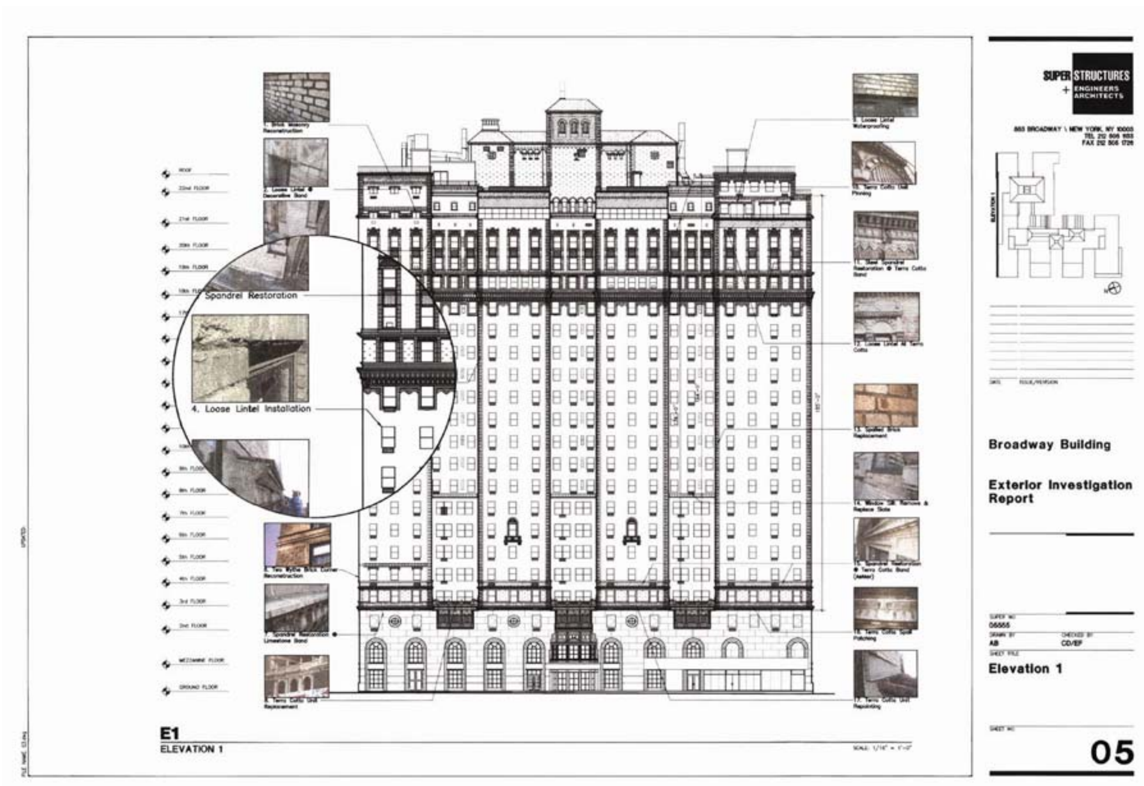

Figure 4-1: Superstructure’s drawing elevation. (Source: Superstructures Engineers and Architects. (2004): *The Red Brochure*. Superstructures Engineers and Architects, New York).

The detail bubble shows an enlargement of the kinds of information displayed by the drawing. Number 4 shows a loose lintel installation requiring correction. It is shown as a detail photograph, taken digitally at the site at the time of data collection, and entered into the CAD drawing at the same time. The photo is then linked to the elevation using lines to indicate its precise location and occurrence on the building. The process continues.

> This level of automation occurs at all stages of the project. We have custom programs that are able to harvest product tags from CAD files and subsequently generate, automatically, the project spec sheets from our in-house library of approved products. We also have a library of hundreds of typical repair details that can be accessed through our proprietary application, the *RAD* [Restoration Assembly Detail] *Catalog*. The RAD catalog allows the user to browse the library hierarchically by typology and then insert the needed details into an existing drawing or to simply pull the detail into its own separate CAD file. (Iverson 2004).

Figure 4-2 shows a sample reproduction of one of Superstructures' construction drawings and illustrates the automation that Iverson described. The example of the loose lintel was documented on site with digital photography. The employee investigating the site entered this condition directly into the CAD drawing by choosing from a drop down menu of repair condition choices. They were then able to quickly input the associated data – in this case, the number of linear feet needing repair. These repair conditions are maintained in a cataloging system call the RAD catalog and are available for insertion into drawings as described above by Iverson.

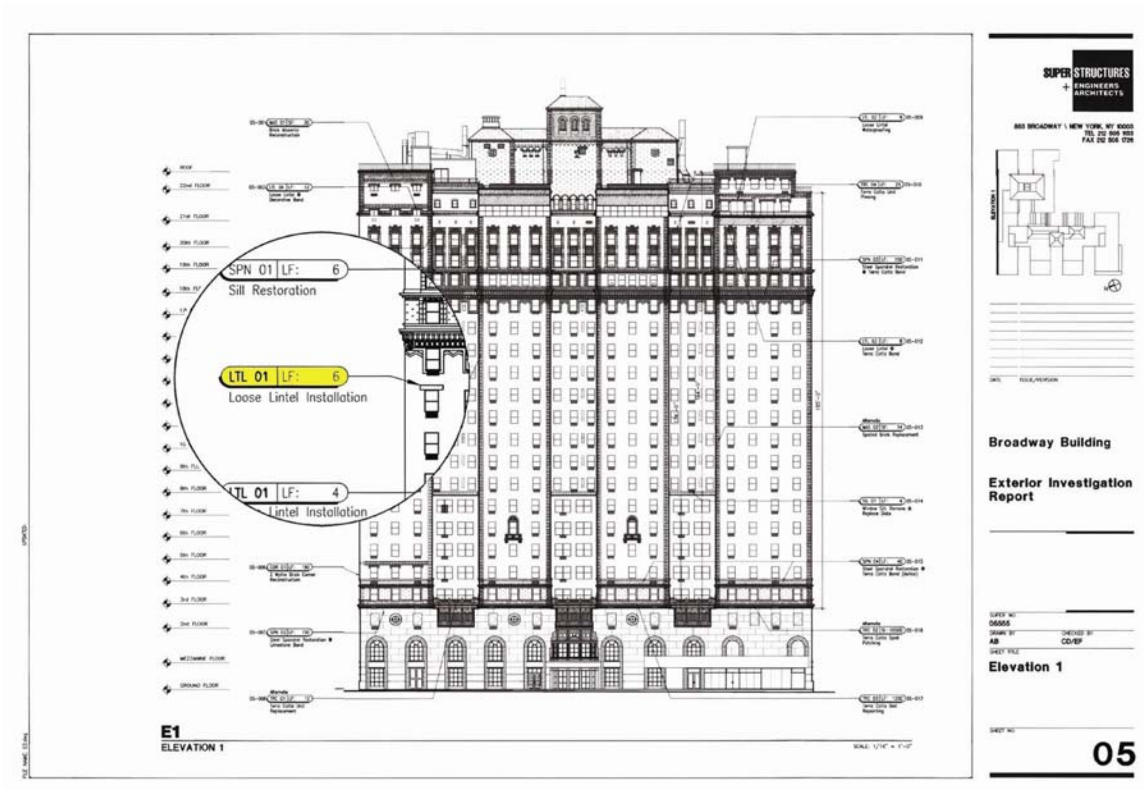

Figure 4-2: Superstructure's drawing elevation showing tag detail. (Source: Superstructures Engineers and Architects. (2004): *The Red Brochure*. Superstructures Engineers and Architects, New York).

The detail bubble shows an enlargement of the same loose lintel installation mentioned above. According to the drawing detail and identification tag, the steel lintel supporting the masonry window opening is loose and requires 6-LF of replacement. (Millman 2004). This is just one example of the kind of information recorded by and displayed in this digital media.

> Back at the office, more custom programming as well as a few proprietary applications allow the user to simply export the data contained within the CAD file with the click of a button. Once exported, the data (containing all estimated types, quantities, and associated photos and comments) is programmatically parsed into an easily understood spreadsheet that can then be easily pulled into any one of numerous report templates to be turned over to appropriate parties. (Iverson 2004).

Because details are selected from an existing inventory, each repair detail has been thoroughly checked for completeness and drawn to office standards. Repair reports, specifications, and product lists can be generated automatically from the pre-drawn Restoration

Assembly Details. These details "depict the arrangement of components and the types of materials involved in each restoration assembly.” (Superstructures Engineers and Architects 2004). Figure 4-3 shows a sample detail drawing that has been selected from the office library. The items in bold typeface will automatically be extracted to generate a list of material items, which in turn will automatically produce all necessary product cut-sheets as provided by the manufacturers.

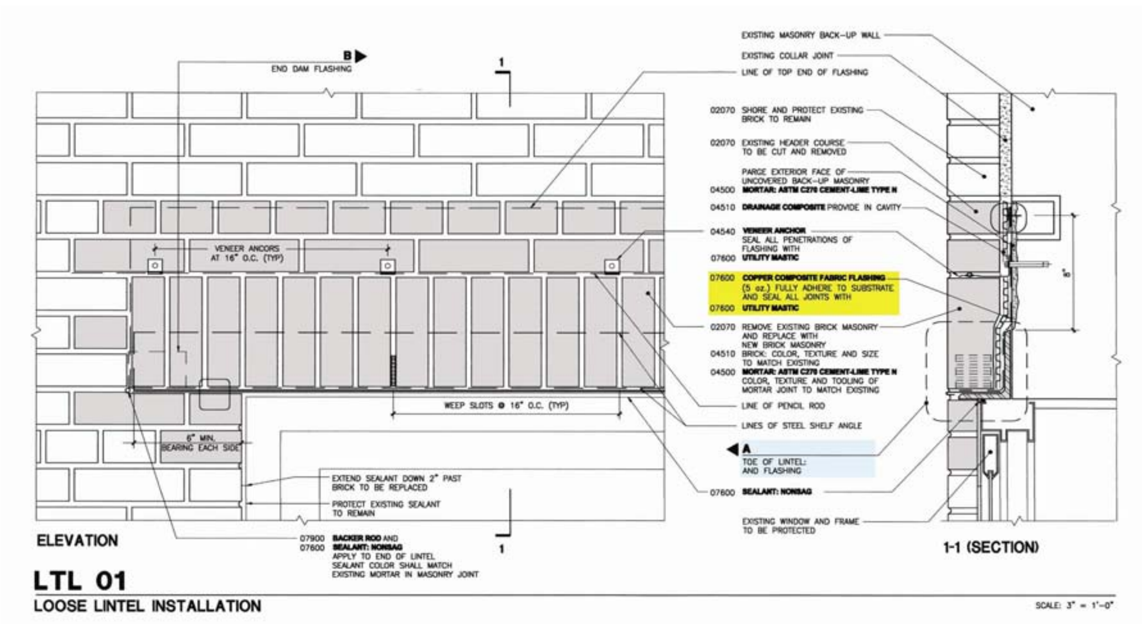

Figure 4-3: Superstructure’s detail drawing. (Source: Superstructures Engineers and Architects. (2004): *The Red Brochure*. Superstructures Engineers and Architects, New York).

LTL 01 is a RAD detailing the installation of the new lintel. These types of drawings provide installation information, product specifications, and locations. LTL 01 specifically provides “the cross-sectional designation of the new steel angle, establishes minimum bearing for the angle, shows the location and extent of new fabric flashing, and the location of drainage weep holes.” (Superstructures 2004). When still greater detail is required for building assemblies, sub-details are created by enlarging areas of existing details. Figure 4-4 is an example of one of Superstructures’ sub-details.

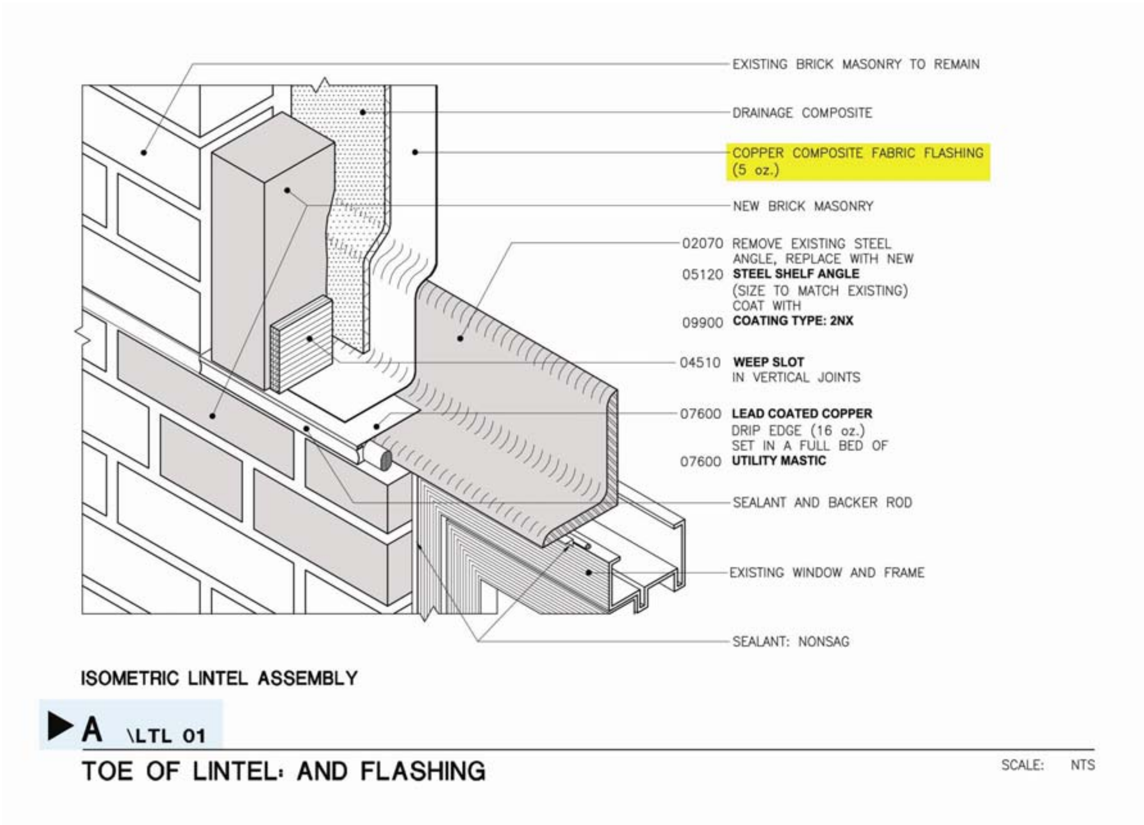

Figure 4-4: Superstructure's detail drawing showing tag references. (Source: Superstructures Engineers and Architects. (2004): *The Red Brochure*. Superstructures Engineers and Architects, New York).

The tags read like any traditional drawing. This sub-detail shows the precise "relationship of pre-formed sheet metal flashing to the toe of the lintel." (Superstructures 2004). Like all of Superstructures' drawings, the isometric detail shown above is customizable based on existing conditions.

Superstructures' drawing details are specific and easy to understand. Although they are presented in the same style and media as standard drawings created by architects for use by construction managers, they contain more usable information and are more universally understood than a traditional set of digital drawings. More members of the project team can read them.

The following chapter will further review the mode of representation used by SEA for managing projects. It will analyze their drawing media and delivery against information borrowed from Communication Theory to demonstrate how proper attention to drawing media can help prevent performance failures to help designers and builders better manage their projects.

CHAPTER 5
ANALYSIS

Introduction

Performance failures occur when there is a disruption of communication between intent and execution. When there is no mutual understanding, the results can include unintended cost, delay, and injury. Therefore, the means of achieving that understanding play a pivotal role in assurance of proper execution and even, to a large degree, determine what kind of information can be shown and how it is perceived. We discussed *mode of representation* as the format of a document and *media* as the vessel of delivery. If this concept seems far-fetched, consider the vessel metaphor from Chapter 2. How much can the vessel hold, how can you put objects in the vessel, and what do the objects look like once in the vessel. Rather than assuming a neutral vessel (or format), this thesis has described and analyzed the traits inherent to a medium (or mode of representation) that shape how creators and users interact with a document. The following traits were identified as relevant to the construction process.

- Facilitates input
- Facilitates alterations
- Limits size and scale
- Facilitates visualization
- Assigns responsibilities, reflects the chain of authority
- Promotes collaboration
- Promotes version control
- Maintains design integrity
- Responds to the level of understanding of project team members
- Allows for appropriate level of detail.
- Promotes ease of reading output
- Communicates scope
- Draws attention to details
- Draws attention to changes
- Saves time disseminating information
- Facilitates accuracy of reproduction
- Facilitates quick decision making
- Demonstrates documentation authority
- Facilitates reviseability

- Manages project members’ expectations
- Provides universal visual presentation
- Documents process

One company, Superstructures Engineers and Architects, was identified for study for its careful attention to its media needs. Effectively, they identified the traits that were relevant to their operations and built a process to reconcile them with their media. They invested considerable time, money, and resources in this problem. While their solution is a work in progress and by no means complete, they have analyzed their representational needs and gone to great expense to create at least a theoretical framework for implementation. The list of traits above was created based on the review of literature and not all of them are applicable to the case study. What follows is an analysis of Superstructures’ mode of representation based on those traits from the list above and evaluated in the previous chapters on Communications theory that were found to be relevant.

Analysis: Causes of Failure

Superstructures’ project management style differs from that of a traditional design firm because they specialize in the exterior restoration of existing buildings and do not create all of the same drawings that would be required for new construction or structural work. SEA therefore operates in a highly simplified world of design and building compared to that of traditional architects and engineers. For the purposes of this research, the limited scope of Superstructures’ projects makes them easier to analyze and presents a more coherent study.

The sections below identify two major sources of media-related performance failure, miscommunication and inappropriate cost cutting, and relate Superstructures’ unique structure to their media requirements and relevant media traits.

Miscommunication

The most pronounced source of media-related performance failure is miscommunication. This type of miscommunication occurs when media displays information that is inappropriate to a user's level of understanding, when the level of detail is inappropriate, when design integrity is lost, when the visualization is ineffective, and when the authority or responsibility for information is unclear. It also occurs when the information input is inadequate, when the media fails to maintain version control, when changes are not easily made and distributed, and when the scale of the document is inappropriate. These miscommunication causes are described in detail, below.

Certain modes of representation have a higher capacity to restrict information to the level of understanding appropriate for users. A project owner will likely be less able to understand a set of mechanical drawings than the mechanical subcontractor who creates the shop drawings. Similarly, an engineer will require different information from a set of structural drawings than would the architect of record. Knowing a medium's responsiveness to these varying levels of understanding influences their creation. Superstructures' target system of representation uses databases for information so that it can be organized and displayed in different formats for different end users. The same data can be shown in spreadsheets when intended for owners and displayed in construction drawings when intended for builders. In addition to promoting understanding during the building process, imagine the benefits this filtration of information could have during the change order process. Relating to Superstructures' specialties, if an unknown field condition were discovered and additional lintel replacement were required, this information could be modified in the database, shown in drawings presented to the subcontractors and spreadsheets to the owner.

Certain media have a higher capacity for detail and therefore a different potential for portraying information. To avoid miscommunication, media must be considered with an eye for the detail needs of users, which affects the selection and input of information into construction drawings. Superstructures' drawing database allows as much information as necessary to be inputted and later filtered for distribution. In this way, the detail will remain appropriate to the document created and its intended users, and the document's creators are not limited in what they can include. Their system even allows for the easy inclusion of site-specific photos, increasing their documents' capacity for detail beyond those created using standard media.

Certain modes of representation do a better job than others of maintaining the creator's integrity of design. Performance failures were first identified in this paper as the failures that occur between intent, communication, and execution, and the same issue is at stake here — making sure that end products match designer's intent. One of the ways that Superstructures' system achieves this is by reducing the number of times each piece of information is handled. Data is collected in the field and entered into the system at the same time, reducing potential for mistakes from transcription, forgetfulness, illegibility, etc. Another feature of their system is standardization. Although details are customizable, nothing is generated from scratch. All drawing details come from the detail library. This eliminates situations where multiple draftsmen work from their own ideas and create drawings with conflicting details, eliminating the potential down the chain that a builder will be conflicted. In an office of many draftsmen, there is potential for many drafting styles. Using a library of pre-drafted details helps to eliminate inconsistencies of style and, in this case, maintains the integrity of the restoration designs of SEA.

Certain modes of representation are ineffective for the conceptualization or visualization of the project. Fischer et al. (2002) report that 3D modeling can reduce the number of review sessions required to ensure a properly detailed design. This is just one example of a mode of representation that improves project visualization for participants. By layering information, details, photographs, and specifications within their system, SEA promotes a common understanding of the project. Their system also promotes accuracy in visualization by drawing from their digital library of pre-drawn details for the vast majority of the production process. Since the details are pre-drawn, they have been pre-screened for accuracy. The CAD system allows for modification of details should they be found inconsistent with existing conditions. Superstructures' project scopes are limited to a degree that precludes the need for most creative conceptualization of a project. They are a firm that specializes in restoring existing conditions rather than creating something new. However, project team members still need to look at their documents and understand the details of the project and how they fit together. A mode of representation that presents a unified vision of the project to the entire project team can provide the outcome of consistent and repeatable interpretations that was touched on by Fischer's technology dilemma in Chapter 1.

Certain modes of representation are ineffective at assigning authority or responsibility to the parties involved. For example, the system used for the Regency Hyatt had very poor assignment of responsibility for design control. It was unclear to the project participants where the final responsibility for decisions lay. By employing an in-house studio of structural engineers, SEA significantly reduces the potential of communication problems with outside sources and the need for assignment of responsibility to outside parties. That is a function of their operational structure, not a function of their mode of representation. However, as a result, the documents they produce reflect that authority to project team members. One way that they do this is through their creation of *Record Sets*– snapshots of the drawing set that are pulled out and copied to a separate folder at various stages of the project (i.e. Owner Review Set, Department of Building Set, 100% Completion Set). At SEA, one-on-one communication between the architects and engineers can happen as needed, resulting in mark-ups and changes to drawings that are made quickly and efficiently. Once the markups have been made, the architect needs only to return to his desk and make the appropriate changes to the CAD file. The alteration process is documented through a series of Record Sets. By making the documentation of process easier, SEA improves the likelihood that it will be done, improving the perceived authority of the drawings being used.

Certain types of media make data input easier than others. Arguably, paper drawings are still the easiest for many draftsmen to create and allow for tremendous flexibility in how information is displayed. This explains why people like the principals at Office dA use paper for their initial project conceptualizations and that most of the work performed by KPF's Design Technology Researcher was done post-rationally, meaning that conceptual shapes were designed (usually on paper) and then worked into buildable designs using various forms of software. Superstructures' system improves the usefulness of digital media by improving the ease of input for data. Through the use of custom software and field computers running full CAD software, SEA field investigators have access to the full list of SEA-approved restoration conditions in simple and easy to use pull down menus. This pre-defined listing eliminates any kind of guesswork on the part of the field investigators and ensures that the assigned condition has a pre-drawn detail back at the office. In acknowledging that ease of input increases the likelihood that a system will be used, SEA improves the usefulness of their media.

Certain modes of representation fail to maintain proper version control of documents. Documents are sometimes created without updated revision numbers or dates or sometimes it is not obvious where to find this information. This can occur when the process required to input this data is cumbersome or if the input process does not require this data. As a result, project team members may not know which drawing version is correct and up-to-date, or even that there are multiple drawing versions. Performance failures can result. Superstructures' folder and file structure is produced automatically at the start of each job. A single master folder contains the working set of drawings (the equivalent of the Mylar set used when drafting by hand). At various milestones throughout a project, a snapshot of these working drawings is pulled out into corresponding folders. These milestones might include owner reviews, Department of Building submittals, or various levels of completion. Thus, there is a record of every project's process that is easy to access. Drawing versions are clearly marked and filed, and everything is linked to the database so that out-of-date drawings are not repeatedly distributed. This improvement in their system begins at the input level and affects the way designer's intent is executed by properly handling document versions.

Certain types of media inhibit distribution of changes to project team members. Perhaps the greatest asset of electronic documents is the ease with which information is disseminated. At SEA all documents originate in electronic form, whether they start as spreadsheet templates or are CAD details imported from the in-house library. CAD drafting used by SEA allows for information to be clarified after the fact in a way that calls attention to changes. Layers are used to present information in varying levels of detail without destroying other information. Layers showing information irrelevant to the changes can be turned off to focus the attention on changes. Details can be displayed in an uncluttered format. Because the documents are tied to a database of information, changing one aspect of the document links automatically to related changes elsewhere in the document. The digital media, coupled with high bandwidth connections to the internet, allow SEA staff to disseminate information to clients, contractors, and other necessary parties through email or FTP sites. Despite greater up-front time investments for creation, digital media reduces the amount of time required to alter, reproduce, and distribute drawings, which also affects the way that users perceive the information in the drawing. Drawings that can be sent quickly speed up the review and revision processes. Information that is passed quickly this way tends to be more up-to-date and accurate and so perceived with more confidence. Increasing confidence helps eliminate variation in interpretation of drawings.

Certain types of media limit drawing size and scale. By using digital media, SEA is no longer limited by physical storage space available in the office. It is possible to accumulate vast quantities of drawings (or multiple versions of one drawing) without worrying about where to keep them. They can be plotted when needed, keeping the amount of office clutter to a minimum. At another level, the size and dimensions of media can limit the amount and type of information that can be physically and legibly fit onto a sheet of paper. Superstructures' use of digital media allows draftsmen to easily organize details on a sheet to optimize the amount of data per sheet.

Inappropriate Cost Cutting

Inappropriate cost cutting is the false economy of saving money by ignoring the performance requirements of your company. This sort of cost cutting is prevalent in the construction industry, and includes things like lack of training and lack of safety programs. What appears to be an up-front money savings can have a high cost, financially or culturally, in the future. This section focuses on avoiding media-related performance failures caused by cheapness and what SEA hopes to achieve by spending money up front.

SEA invested early in both the use of computers in the workplace as well as in the customizable nature of the CAD system. This early adoption was initially a large financial investment, but one that has paid off many times over in productivity and output. Because the system was implemented before many firms embraced the electronic drawing format, SEA has managed to stay ahead of the competition by investing its time in researching new technologies as well as refining its current system. (Iverson 2004). Lamendola and Lamendola (1998) blame the poor quality of working drawings on inappropriate cost cutting. They go on to explain,

> A major impetus behind the deterioration in drawing quality has been cost-cutting in the name of delivering a set of drawings under a reduced fee. Anyone who's had to deal with poor documentation or poor as-built drawings knows the false economics of this approach…One useful solution to the cost reduction problem is Computer Aided Drafting (CAD). Unfortunately, many firms implemented CAD without considering traditional drafting principles or the needs of the people using the drawings… This resulted in many CAD users wiping out the cost savings the software would otherwise provide them. So, not only must we contend with poor working drawings, but we also must deal with poor electronic sources of those drawings." (Lamendola and Lamendola 1998).

By investing not only money in the creation of their system but time in training employees to use their system, SEA hopes to avoid the problems outlined above: lack of employee training in using a system, misuse of money, misuse of technology, all resulting in drawings that fail to convey information between creators and users.

Analysis: Solutions to Prevent Failure

What does a company need from their drawings? To answer this question, a company can ask itself three questions: What information should be contained, how should it be inputted, and how is the information presented once the document is created? The answers to these questions will form a company's mode of representation. If a company never asks itself these questions, it will use what is familiar and what is readily available. However, there are some innovators that are revising their expectations and beginning to re-evaluate their media needs. They are revising their expectation to do business as usual, that ongoing problems can be solved within the system that created them. They are revising their expectation of what media is, what is needs to do, and how it should be created, revised, and distributed. Their revised expectation is that they will put some effort into creating a mode of representation that works for them. This is a productive direction for a company to take.

SEA demonstrates awareness that attention to mode of representation potentially results in better project coordination, ease of input, and a customizable display of detail that is easy for all project participants to understand. Iverson (2004) said,

> We have effectively eliminated most of the steps where information breakdowns occur by automating processes that were either tedious or simply overwhelming for a human being. In doing so, we have also freed the human element to do what it is best at - interpreting data and making subsequent decisions. (Iverson 2004).

Although “it is ultimately humans that must first gather the appropriate data, understand how to interpret that data, and finally to organize it in a way that is easily understood by outside third parties,” proper understanding of media and intelligent application of technology and automation can improve communication and reduce performance failures on construction projects. (Iverson 2004).

The following traits are typical to Superstructures’ representational system and contribute to smoother completion of projects:

- Electronic documentation and communication
- Standardized drawing and data modules
- Standardized presentation
- Single entry point for data and revisions
- Single project document
- Filtration for various users
- Transformation for management (cost accounting) and for customers (presentation).

Their electronic format reduces time for revisions and distribution. It allows SEA to link drawings to databases so that information can be rapidly revised and distributed. The electronic format also makes all of the following points possible. The standardization of drawing and data modules increases ease of input for users by offering a standard set of solutions to choose from for solving restoration problems. Standardized presentation speeds the creation of a document and improves readability for users. Having a single entry point for data and revisions (the project database) automates linking changes throughout a document so that revisions are consistent. Having a single project document reinforces the authority of the document and revision status. Using a database and filtering information specific to users allows document creators to tailor information to users without having to limit the way in which they input the information. The net result of these functions is that SEA can transform their documents for internal or external presentations, providing information that is specific and understandable to the user, without having to create a new document each time or to limit information in their document.

Performance failures occur when there is a disruption of communication between intent and execution. When mutual understanding is not achieved, the results can be disastrous. One way to prevent these disruptions is to examine the way that information is handled and to modify the system based on engaging communication and collaboration, facilitating change making and distribution, and improving ease of use and interpretation by users. Superstructures' system, their mode of representation, creates a unified document that links information together in functional ways. Rather than allowing available systems to dictate to them, they are innovating based on their actual needs.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

Conclusion

The medium in which construction documents are embodied is critical in bringing about either success or failure in performance on a construction project. *Medium* was described in this thesis as the vessel containing information, and *mode of representation* as the format of the presentation of information or the larger system employed for communicating. This thesis assumes no neutral vessels. That means that the medium of a document affects the content of the document in some way. Two different ways were examined: effects on how creators organize information in a document and how information is perceived by document users.

This thesis related the following points:

- Each medium has its strengths and weaknesses. The traits are referred to as *communication bias* and they relate to how media influences creators of documents and users of documents.

- Construction documents are more likely to reflect tradition and conventional technology than to meet the needs of their creators and users. This problem reflects a general industry-wide tendency to stagnate, avoid change, and economize at the expense of improvements.

- The ultimate result of ineffective documents is performance failure. Media-related performance failures result from miscommunication and inappropriate cost cutting. Human-related performance failure is difficult to predict or combat, but failures that result from ineffective documents are inexcusable. The Hyatt collapse precipitated changes in building codes, in engineering practices, practices regarding the review and approval of drawings, and in the assignment of responsibility for shop drawings. It should also be used as a platform to begin examining the need to change the documentation systems themselves, and was the starting point of this thesis.

- The ultimate benefit of effective documents is improved communication and predictable and reliable communication between project team members.

There is a path toward improvement; however, few companies are willing to attempt to create their own mode of representation, their own comprehensive system of construction documentation. Without questioning traditional systems and investing time and money up front, designers and builders will not make the changes necessary.

One company, Superstructures Engineers and Architects, specialists in exterior restoration, was found for study that has attempted a comprehensive solution and has found benefits that outweigh the development and training costs. SEA analyzed their performance needs and created a framework to implement a new mode of representation. Their system is comprehensive, unified, and promotes precise, consistent interpretations of documents. Their documents are created by storing information related to the project in a database. Drawings are created in CAD and linked to the database. Field conditions are documented in the field and inputted directly into the document without need for transcription back at the office. Photos, standard details, and specifications are all linked to the drawings. When changes are made to the database, they are reflected everywhere throughout the document. Their system is successful on a number of levels. It produces drawings and related documents that utilize standard drawing conventions but are easier for all project participants to grasp because of their incorporation of details and photographs. Their system reduces the number of times each piece of information is handled before it is incorporated into the document by allowing for easy data input in the field. Their system is based on a database rather than isolated documents so that changes may be incorporated across the entire document from a single point of entry. Their system also allows customizable presentations of information, allowing creators to include information that would otherwise be unintelligible for certain users and providing users with documents tailored to their interests.

Recommendations for Future Studies

This thesis makes no claims to chart the quantitative successes of SEA, only to document their qualitative successes. It would appropriate as a follow up study to identify corresponding quantitative qualities of their operation for comparison over time or with other companies. Tracking the performance, financial or otherwise, of one of these innovative companies against a company using more traditional media may support or qualify the claim that up-front investments in media produces measurable improvements in performance, financial or otherwise.

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BIOGRAPHICAL SKETCH

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