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A mixed methods study on choice of media influence on construction industry communication

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A MIXED METHODS STUDY ON CHOICE OF MEDIA INFLUENCE ON CONSTRUCTION INDUSTRY COMMUNICATION

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Dedicated to my parents,

for supporting me and for always believing I could do this.

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ABBREVIATIONS

AECO	Architecture, Engineering, Construction, and Operations
AGC	Associated General Contractors of America
AIA	American Institute of Architects
ANOVA	Analysis of Variance
BCM	Building Construction Management
BIM	Building Information Modeling
CM	Construction Manager
CMC	Computer Mediated Communication
CO	Change Order
HTML	Hypertext Markup Language
IRB	Institutional Review Board
ICT	Information and Communication Technology
IT	Information Technology
MRT	Media richness theory
OSHA	Occupational Safety and Health Administration
PSVT	Purdue Spatial Visualizations Test
RFI	Request for Information
ROT	Purdue Visualization of Rotations Test
FTP	File Transfer Protocol
VOIP	Voice over the Internet Protocol

ABSTRACT

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This study focuses on the use of different communication media for solving problems in the construction industry. The focus of this research is on design-problems containing spatial information and are informally reported between site supervision and design professionals. Due to the fragmented nature of the construction industry, miscommunication is a well-known and common problem. Yet, this fragmented nature is necessary in order to build a complex product involving many different types of professionals. To better understand the issue, this study uses previous literature, such as those published on media richness theory, problem-solving strategy, and construction specific communications, in a three-phased sequential mixed-methods approach. The phases included an online survey with industry professionals (phase 1), interviews with industry professionals (phase 2), and a quasi-experiment (phase 3). Quantitative and qualitative data were analyzed depending on the phase. Results indicate that construction industry communication relies strongly on face-to-face interaction, and telephone and email communications. The need for a 'paper trail' is an important factor driving communication patterns. Finally, phase 3 suggested that communication media that allow for immediate feedback and visual cues are more helpful in solving design-problems containing spatial information. Based on these results, guidelines for effective use of different types of media in the construction industry were then developed as a final product of this study. These guidelines seek to improve awareness about the importance of effective communication in the construction industry.

CHAPTER 1. INTRODUCTION

The main goals of this chapter are to provide an overview of the problem and to present the research questions planned for this study. Specific assumptions, limitations, and delimitations are also described. At the end of this chapter, the researcher presents definitions of key terms for this dissertation.

1.1 Nature of the Problem

Communication in the construction industry is essential for effective flow of information between all those involved in the process (Dave & Koskela, 2009; Emmitt & Gorse, 2003; Gorse, Emmitt, & Lowis, 1999; Mohamed, Tilley, & Tucker, 1999). The essence of construction documents, design documentation included, is to store and transmit information among stakeholders in the industry (Dave & Koskela, 2009). It is a communication process between agents. Figure 1.1 illustrates the process of communication, which can be understood as the act of transmitting information from one person (or persons) to another (or others), using a communication medium (Chiu, 2002; Sekaran & Bougie, 2010). The goal of communicating is to achieve a shared understanding so that decisions can be made (Sonnenwald, 1995).

Shared understanding in the construction industry is difficult due to its multidisciplinary and temporary nature (Bresnen, Edelman, Newell, Scarbrough, & Swan, 2003; Emmitt & Gorse, 2003; Gorse et al., 1999; Holzmann, 2013). In the Architecture, Engineering, Construction, and Operations (AECO) industry, teams of diverse professionals come together to work on a project. Once the project is concluded, this partnership is dissolved and professionals move to the next project, in which they will most likely have a different set of partners. If on the one

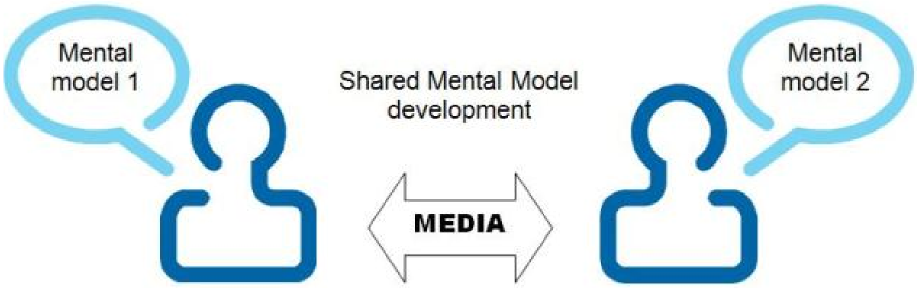


Figure 1.1. Communication process

hand this diversity can be a source of communication difficulty, on the other, the broad range of professionals working in construction is essential because of the complex nature of buildings. Cheung, Yiu, and Lam (2013) and Gorse et al. (1999) indicated that effective communication among construction stakeholders can reduce risk and improve coordination in the AECO industry.

Enabling a shared understanding is a way to improve the chance that the recipient of the message understands the point of view of the person who originates the message, also known here as communicator. Research on shared understanding related to design in general found that difficulties arise due to conflicting interests and field specific jargon used by professionals (N. Y. Cheng, 2003; Sonnenwald, 1995, 1996). Bucciarelli (2002) even describes the jargon of construction designers as elite and the problem of "translation" between diverse technical languages as one of the most challenging problems in design.

Although multidisciplinary communication has its challenges, Denton (1997) indicates that companies in general are interested in having multidisciplinary teamwork. The attempt to merge disciplines in education is also a current desire of organizations that oversee K-12 education (International Technology Education Association, 2007, 2002, 2000; National Research Council, 2012). Other researchers have mentioned this characteristic as a growing trend in companies that deal with design (Sonnenwald, 1996). Mental models is a concept that can be used to better understand the difficulties of communication between professionals from different backgrounds. Mental models are simplified versions of reality that are constructed by each individual, based on previous experience (Johnson-Laird, 2006; Jones, Ross, Lynam, Perez, & Leitch, 2011). An indication of this can be seen in Bucciarelli (2002). In his text, Bucciarelli (2002) does not explicitly mention mental models when he explains different languages, but he does acknowledge that one object can have different levels of significance between different people and different stakeholders within the same design. This idea is compatible with the mental models concept, since this diversity is based on individual differences.

Two additional concepts that help understand how different professionals work together are team mental models and shared mental models. Both are related to the mental models concept. A team mental model is different from a shared mental model in that a team mental model "...refers to shared cognition in a team as a collectivity, not shared cognition among dyads of individuals, which the alternative phrase 'shared mental models' does allow" (Langan-Fox, Wirth, Code, Langfield-Smith, & Wirth, 2001, p. 99). The idea of team mental models is linked to improved team effectiveness. This happens because while performing a team task, all members will share a similar understanding of the task and the resources available (Mohammed & Dumville, 2001). This is especially important in the AECO industry. Collaboration in construction work is a common practice (Dave & Koskela, 2009; Liu, 2009). Teams are organized with a shared goal to design and build a project (Emmitt & Gorse, 2003; Peng, 1994). Therefore, the existence of a team mental model is necessary in order to assure that members are aligned, deliverables are known to all, and communication difficulties are reduced.

Besides the multidisciplinary nature of the construction industry, another issue to have in mind is that the ever growing information and communication technologies (ICT) have led to the rise and use of new communication media. In the past, a design was built based upon drawings, physical models, and face-to-face coordination between architects, designers, construction managers, and workers. Now information and documentation can be exchanged not only through printed copies and physical models but also as electronic files and virtual models. Emmitt and Gorse (2003) report a variety of communication channels from which professionals in construction can choose, although their research was performed more than ten years ago. Since then, new media and more intensive use of different media types have emerged, such as the rise of email.

Informal communication between stakeholders to obtain information prior to formalizing an issue has also changed in recent years. Now, along with face-to-face meetings and phone calls, construction professionals can use emails, wikis, instant messaging, and other media of communication. Dave and Koskela (2009) have conducted research on knowledge management in construction across new and different types of online collaborative networks, such as wiki and online forums.

Research on communication has shown that different types of media may influence how a message is perceived by the receiver of the information. Sproull and Kiesler (1986) have researched the differences in communication between peers encountered in face-to-face contact versus email. Media Richness Theory (MRT) and Media Synchronizity Theory (MST) also help to explain the impacts of choice of media to the information being conveyed (Daft, Lengel, & Trevino, 1987; Fox, Leicht, & Messner, 2010; Sun & Cheng, 2007). Communication theory researchers have also questioned the reasons for a person to choose one media over another. For example, media richness theorists argue that the choice of media is made based on the characteristics of the medium and the content of the message (Webster & Trevino, 1995).

Given the recently emerging information technologies available for communication in the construction industry, there is a need to further explore how design information can be transmitted between stakeholders and used in problem solving environments. The construction industry is based on teamwork and exchange of information by formal means (design documents, change orders, requests for information, emails), or informal means (phone calls, text messages, emails, online instant messaging). For example, a change order is a formal means of exchanging information during construction, and it indicates changes in the original project regarding scope, cost, or schedule (O'Brien, 1998). Design related issues are indicated by Gould and Joyce (2003) as a common cause for change orders (COs). Also, requests for information (RFIs) are directly linked to the projects design quality, which means that poor design and lack of information results in more RFIs for a construction project (Mohamed et al., 1999).

But the construction industry does not depend only on formal types of communication or documentation. As mentioned before, it is common for stakeholders to communicate using informal means, such as telephone, email, and face-to-face contacts (Emmitt & Gorse, 2003). This is the reason most knowledge in the construction industry is considered to be tacit, which means not formalized or explicit to others (Dave & Koskela, 2009; Lin, Wang, & Tserng, 2006).

Even though the importance of effective communication in design and collaborative work is well known (Chiu, 2002; Peng, 1994), little recent research has focused on the influence of the choice of media within construction. Liu (2009) has done some research focusing on communication in general at the construction stage. His focus was general, and not about media and its impact on construction communications. Fox et al. (2010) have studied how teams react to the same information provided to them through different media. Even though media input was different, all teams worked in a face-to-face environment. Also, Emmitt and Gorse (2003) have demonstrated the importance of effective communication in the construction industry. Even though their research is a valuable asset for the field of construction communications, the aforementioned authors have not studied specifically how problem solving is affected when participants use different media during the process. This present study aims to fill this gap by providing more information about problem solving of design issues in construction, specifically when using different types of media for group interaction. Even though this research focuses on construction, issues such as multidisciplinarity, communication, and problem solving are considered important for learners and professionals from all disciplines (National Research Council, 2012).

1.2 Statement of the Problem

Research in the field of communication says that some communication media can yield more social cues than others (Webster & Trevino, 1995). These cues can be beneficial for communicating information between peers by improving understanding. Construction is a fragmented industry based on teamwork that, by itself, uses multiple languages at the same time. However, there is a constant need for effective communication in the industry in order to deliver its products on time and error free. Communication difficulties due to different languages are frequently studied, especially in design teams. However, little research has been done on the influence of channels for solving problems in construction communication that require design and construction personnel interaction. This study provides a mixed-methods approach to understanding the processes and strategies that field and design personnel employ while using different media for solving and discussing spatial problems related to design. In this research, spatial problems are tasks that involve positioning and repositioning elements in space in order to solve an issue.

1.3 Purpose of the Study

The purpose for this three-phase, mixed-methods study is to understand how informal means of communication are used between field and design teams for spatial design problem solving. The final goal of this dissertation is to create guidelines to improve construction communication within teams during problem solving situations. The first phase will collect quantitative information about which media are perceived as most helpful by industry professionals. Then, a more thorough qualitative study will be conducted to understand the reasons underlying the first-phase findings. Finally, a quasi-experiment will be conducted using students and professionals from construction-related fields to understand their problem solving and communication strategies for dealing with constraints originating from the media used for communication. Data from all phases will contribute to the creation of guidelines for students and young professionals that will help them communicate about spatial problems through media channels.

1.4 Research Questions

1. How does the choice of media influence problem reporting and problem solving between field and design teams?
   (a) Which are the main media of communication between site and design teams when reporting spatial problems related to design?
   (b) What are the advantages and disadvantages of each of the most helpful media?
   (c) What are the perceptions about effectiveness, difficulty, and strategy students and professionals in construction related fields have about the main media of communication?

The objectives of this study include: to understand issues of reporting spatial problems to different stakeholders in the construction industry, many of whom have different backgrounds and specialized jargon; to understand strategies used to solve spatial problems while addressing possible limitations by the media chosen for communication; and to propose guidelines for improving spatial communication related to problem solving for students in construction related fields.

1.5 Significance of the Study

Many researchers acknowledge that construction is a multidisciplinary industry and that communication between stakeholders is crucial for the good development of projects (Dave & Koskela, 2009; Emmitt & Gorse, 2003; Shen et al., 2010). Papers on collaboration have been published regarding issues on design teams (Perry & Sanderson, 1998; Sancar, 1996; Stempfle & Badke-Schaub, 2002). Sonnenwald (1995) work on contested collaboration has provided an important model for the analysis of design team dynamics. However, with the exceptions of Gorse and Emmitt (2007, 2009), few research have studied communication between construction management personnel and the design team during the construction stage.

Media richness theory is one of the first to try to explain differences between media channels in terms of types of information sent or received. Webster and Trevino (1995) indicate that richer channels allow for more cues to transmit the message. For example, emails do not have tone of voice or gesture cues, while with a face-to-face communication, the sender may emphasize issues with tone of voice or hand gestures. Hand gestures are helpful for spatial communication (Austin & Sweller, 2014; Johnson, Cocks, & Dipper, 2013), which can become helpful in a construction setting.

Research regarding media communication in the construction industry is small but constantly growing due to recent advances in information technologies. Liu (2009) has surveyed more than 100 construction related companies about communication and collected information regarding media and preferred forms of communication. Fox et al. (2010) have studied the influence of media synchronicity in the Architecture, Engineering, Construction and Operations (AECO) industry by performing a mixed methods study based on interviews, quasi-experiments, and focus groups. Dave and Koskela (2009) have studied more recent media, including Web 2.0 tools such as instant wikis and internet forums. Other researchers have focused on design teams, analyzing data from online design studios (Peng, 1994; Sancar, 1996). As one can see, the literature about communication in construction industry is scattered.

In addition to communication issues in construction, design issues during the construction phase can also be related to communication issues. Frequent reasons for design problems in construction are lack of information, conflicting information, constructability issues, or changes in scope. These might result in the filing of requests for information (RFI) or change orders (CO) (Gould & Joyce, 2003; O'Brien, 1998). When this happens, the field crew must describe the problem or conflict and communicate with the design crew and sometimes the client to find a solution. Most RFIs and COs are formal documents. Recently, there has been an increase of using electronic means to file these documents. But informal communication between stakeholders in construction is frequent (Emmitt & Gorse, 2003). Liu (2009) and Emmitt and Gorse (2003) have enumerated some of the means of communication most frequently used by English and Chinese construction companies, but since then, email and online file sharing have grown. E. W. Cheng, Li, Love, and Irani (2001) indicate that media such as email, telephone, and teleconferences are a good way of communicating with distant collaborators in the construction industry.

In light of the information above, this present study has significant value in gathering information about recent media formats, and their implications in communication between site and design teams. Few studies have approached this interaction. This study also provides input about educational perceptions pertaining to problem solving strategies. The researcher will use the studies on problem solving and design problem solving by Jonassen (1997), Newell and Simon (1972), and Stempfle and Badke-Schaub (2002) to analyze different strategies used for industry specific issues. To help understand the results obtained, this study will also build on previous works about problem solving, expert and novice differences, and cognitive strategies for solvers to improve problem solving skills, such as metacognition and epistemic beliefs and strategies.

The significance of this study lies in connecting communication and problem solving in a specific construction industry setting. There is a constant demand for construction to improve its effectiveness in order to reduce time of construction and errors. New information and communication technologies are currently being tested and used in the pursuit of this goal. Communication and teamwork are critical to a project's success (Cheung et al., 2013) and are also seen as necessary outcomes of undergraduate accredited construction management courses (American Council for Construction Education, 2014). This research does not plan to propose a new technology but rather to study how professionals and students in construction can improve communication effectiveness using the media already available to them.

1.6 Assumptions

The assumptions for this study include:

- Respondents answered the online survey and interview questions truthfully;
- A reasonable rate of response was achieved;
- The sample for the online survey is assumed to be a significant representation of the United States' AECO industry;
- No new media has evolved or is being used between the period of information collection by survey and the experiment conducted with students;
- Volunteers that participate in the quasi-experiment phase portray an accurate representation of how they would act while facing a design problem in a real professional environment;
- It is assumed that professionals with four or more years of full time industry experience will accurately represent expertise skills and that students with one year or less of full time experience will accurately represent traits of novice learners in the construction industry;
- It is assumed that the research methods chosen for this study are adequate to answer the proposed research questions.

1.7 Limitations

The limitations for this study include:

- Due to time and resource availability, target companies for the investigation only include general contractors and architectural design firms in the United States;
- The construction area of companies may include residential, commercial, healthcare, institutional, and industrial;
- After phase one, this research focuses only on the three main types of communication media that will be determined by the first phase of the study;
- Students used in the experimental research component of this dissertation will be from construction and design related fields coming only from Purdue University.
- The presence of the researcher during the quasi-experiment may influence participants' behaviors and attitudes. The Hawthorne effect may be present.

1.8 Delimitations

The delimitations for this study include:

- This study only focuses on design problems reported by the site and field construction professionals to the design team through informal communication. Official responses for requests for information (RFIs), and change orders (COs) will not be analyzed;
- Design problems in this dissertation are limited to spatial issues, and not managerial issues or issues dealing with substitution that do not affect spatial relations (such as color changes);

- This research does not focus on the influence of gender and personality traits in problem solving, although the researcher acknowledges that those exist and may influence outcomes;
- Companies whose focus is heavy civil, demolition, and repair and restoration services are not included because they might not have architects in their work teams;
- Communication is dependent on cultural behavior and social cues. Because of these influences, findings of this dissertation only refer to the types of construction companies mentioned above, while acting in the United States;
- The focus of this research is not to suggest the best media to be used on construction communication but to understand strategies behind their use.

1.9 Definitions

In the broader context of thesis writing, the following definition of terms will be used:

Collaboration: "Collaboration refers to a group of people working together to accomplish an agreed task or address an agreed goal. Often this could not be accomplished by an individual" (Chiu, 2002, p. 188).

Epistemic beliefs: "[are] standards for the evaluation of information that is to be learned" (Hofer & Sinatra, 2009, p. 115).

Expert: "[presents a] superior performance in representative tasks in the field of expertise" (Björklund, 2013, p. 135).

Media: "The medium of communication is the tool or technology used to transmit the requisite information" (Liu, 2009, p. 42).

Mental Model: "Mental models are conceived of as a cognitive structure that forms the basis of reasoning, decision making, and, with the limitations also observed in the attitudes literature, behavior" (Jones et al., 2011, p. 46).

Metacognition: "[Metacognition] consists primarily of knowledge or beliefs about what factors or variables act and interact in what ways to affect the course and outcome of cognitive enterprises" (Flavell, 1979, p. 907).

Novice: "[A person who] undergoes training and education in their chosen field, and then at some later point becomes an expert" (Cross, 2004, p. 428).

Shared Understanding: "Shared understanding is a similarity in the individual perceptions of actors about either how the design content is conceptualized (content) or how the transactive memory system works (process)" (Kleinsmann & Valkenburg, 2008, p. 371).

Teamwork: "...people working together to achieve something beyond the capabilities of individuals working alone" (Marks, Mathieu, & Zaccaro, 2001, p. 356).

Transactive memory system: "[is] a set of individual memory systems, which combines the knowledge processed by particular actors with a shared awareness about who knows what" (Wegner, 1987, p. 186).

1.10 Summary

This chapter provided an overview of the present research, including the research questions and the statement of purpose. Assumptions, limitations, and delimitations for study are indicated also in this chapter, as well as the main definitions of terms that will be used across this dissertation. In the following chapter, previous works that sustain the main concepts of the dissertation will be presented in order to provide a solid base for the theoretical framework of this study.

CHAPTER 2. REVIEW OF RELEVANT LITERATURE

In this chapter, the researcher provides an overview of the available literature to better understand the problem in sight. This dissertation uses communication and cognitive science research to improve understanding about the interaction between field and design personnel in the construction industry.

First, construction industry issues are presented to contextualize readers with the field in which the research takes place. Then, theories on communication are presented, with a special focus on media richness theory (MRT). This theory indicates that different media of communication allow for the existence of more or fewer communication cues.

Mental models are presented after communication because they can be taken as aids to the cognitive process behind mutual and shared understanding. Even though the research will not directly assess mental models in construction, this is an important concept that affects problem solving. Within problem solving, the author will present works on problem solving strategies, novice and expert differences, and cognitive strategies such as metacognition and epistemic beliefs. Also in this subsection the author will acknowledge two other factors that affect group problem solving: gender and personality.

Finally, literature sustaining the choice of methods used in this study is presented to readers before a summary is presented for this chapter.

2.1 Communication in Construction Industry

As mentioned in the previous chapter, the construction industry is fragmented, and it depends on the collaboration of numerous stakeholders (Chan & Sher, 2014; Dave & Koskela, 2009; Emmitt & Gorse, 2003; Grilo, Zutshi, Jardim-Goncalves, & Steiger-Garcao, 2013). It is also unique, which makes it different than the standard manufacturing industry. H. Li et al. (2008) indicate three main differences between the Architecture, Engineering, Construction and Operations (AECO) industry and the manufacturing industry, based on their experience. The differences are:

- There is no well-established platform to gather and re-apply knowledge from different phases or projects;
- There is no fixed production line;
- It is not possible to fabricate an exact prototype (as in a real size scale) of the building before construction.

The industry is also known for being a slow adopter of new technologies. This seems to be changing in recent years, due to advances in information technologies for construction and pressure for improvements in processes (Dave & Koskela, 2009). Some new technologies on the marked that have been implemented are related to visualization and information, such as Building Information Modeling (BIM), and others focus on knowledge management and improvement of information transmission. Dave and Koskela (2009) have conducted studies about using Internet forums and Wikis to improve information sharing during construction.

Much research about BIM has been conducted over the past few years. The actual industry usage of this technology or process improvement in industry is still taking place (Ding, Zhou, & Akinci, 2014). Miettinen and Paavola (2014) refer to this change as a complex phenomenon with several implications for the future of the AECO industry. The primary concept for BIM has evolved from the parametric modeling done in the manufacturing industry during the second half of the twentieth century. A BIM model consists of a virtual three dimensional model with parametric properties, and that also takes non-geometric information (Eastman, Teicholz, Sacks, & Linston, 2011; Grilo et al., 2013). Miettinen and Paavola (2014) indicate that "BIM is also emphatically a tool of collaboration [...] The collaborative use of BIM reduces design mistakes and increases the productivity of the construction industry"(Miettinen & Paavola, 2014, p. 84). The emphasis given in improving collaboration indicates the importance of this concept for the effectiveness of information flow between AECO professionals.

Ibem and Laryea (2014) have indicated that research about available digital technologies for construction is still insufficient. Trying to fill this gap, they have identified more than 20 different digital technologies currently used in construction. Within the ones they have identified, some are collaboration and information flow technologies such as web-based project portals and web 2.0 technologies. Web 2.0 is regarded as the evolution of hypertext markup language (HTML), and means that: "Online users can not only read, but also insert their own web content in the era of Web 2.0, by using simple Internet tools" (R. Y. M. Li & Poon, 2011, p. 73).

Web 2.0 technologies also refer to social networking portals such as social network sites, online forums, and Wikis that can be edited by employees. In this sense, knowledge in the web 2.0 phase is socially built by people through online interactions. As mentioned previously, Dave and Koskela (2009) have performed a study about the implementation of an online forum in a construction company. They were trying to improve the knowledge sharing process from one project to another, especially in regards to transmitting tacit knowledge and transforming it in explicit knowledge. Tacit knowledge is "...knowledge housed in the human brain, such as expertise, understanding, or professional insight formed as a result of experience" (Woo, Clayton, Johnson, Flores, & Ellis, 2004, p. 203). This type of knowledge is derived from a personal experience and it is not formally established or written somewhere. On the other hand, explicit knowledge is acquired indirectly, after its formalization into documents. Kanapeckiene, Kaklauskas, Zavadskas, and Seniut (2010) indicate several documents which carry explicit knowledge:

> Such knowledge may be found in organizational documents, including reports, articles, agreements, manuals, patents, drawings, video and audio materials, software and such. It may also be found in

> organizational documents such as a company's diagrams, charts, tables, process plans, the wording of a mission and its experience and the like. (p.1206)

The construction process relies heavily on the professional experience, or tacit knowledge, of its professionals (Dave & Koskela, 2009; Kanapeckiene et al., 2010; Nesan, 2012). Nesan (2012) says that the overuse of tacit knowledge in the AECO industry is one of the causes for difficulties in managing knowledge within that industry: "the motive behind decisions is often not recorded or documented; it requires a complex process to track and record thousands of ad-hoc messages, phone calls, memos, and conversations that comprise much project-related information" (Nesan, 2012, p. 48). Emmitt and Gorse (2003) also indicate that construction projects are normally temporary partnerships established per project. Once the project is over, this partnership is dissolved and other, new partnerships are established for new projects. Also, the members of the project group can change according to the phase of the project, and this also increases the fragmented nature of the AECO industry.

The multitude of professionals from different companies and backgrounds also enhances the importance of trust within a project (Cheung et al., 2013). Research shows that trust influences communication and communication influences project performance (Cheung et al., 2013). Nesan (2012) indicates that trust also influences knowledge sharing within AECO companies: "Trust reduces risk and uncertainty through better communications. Communication and the ability to work in teams are seen as the basis for trust building" (p. 50). The author also indicates that face-to-face communication in construction serves as a trust building experience among stakeholders (Nesan, 2012) and is better for complex communication (Cheung et al., 2013). Even though face-to-face is seen as most effective Gorse and Emmitt (2007), Cheung et al. (2013) indicates that several other communication media are also available for use within the construction industry, such as email, telephone, and fax (Gorse & Emmitt, 2007).

Another usual concern of stakeholders within the AECO industry is liability issues. Schoenwetter and Carver (2008) when discussing legal strategies for construction companies, mention: “Information is power. Communication breeds accountability. Regular communication [. . .] provides in-house counsel with the power they need to manage their internal clients.” (p. 6). The need for an information record is emphasized due to the recurring need for written notices during the construction process (Levin, 1998).

Written notice is often mentioned as a contract requirement for notifying parties about changes, and possible future claims (Kelley, 2013). Standard contracts such as the ones managed by the American Institute of Architects (AIA) and the Engineers' Joint Contract Documents Committee (EJCDC) indicate this need for written communications. However, oral communication might also be accepted under certain and very specific situations (Kelley, 2013; Levin, 1998). For example, the Federal Acquisition Regulation (FAR) provisions indicate that oral communication by the client may be accepted if followed by written confirmation (Levin, 1998). The FAR “also serves as a model for many state and local government construction contracts.” (Levin, 1998, p. 3).

Given the issues affecting communications in construction and in order to determine the effectiveness of communication channels used in the AECO industry, Gorse et al. (1999) surveyed construction professionals (architects and construction managers) in England about their perceived helpfulness. Researchers found that channels ranked in the following order, with one being the most helpful (Gorse et al., 1999, p.154):

1. Face-to-face;

2. Written letter and faxes with drawings;

3. Verbal over the telephone and written faxes;

4. Written posted letter without drawings and email with drawings;

5. Email.

Even though results are interesting, it is important to note that research conducted by Gorse et al. (1999) was performed in the late 1990's, when email usage was not as frequent.

Now that issues regarding communication in construction have been presented, a brief overview of the design and initial construction process will be given to inform readers about the construction phases this dissertation will address. This description is based on literature and also on the professional experience of the author.

Initially, the design can be developed by the architect, working directly for the owner (in cases of design-bid-build contracts) or together with a construction company (in the case of design-build contracts). The architect is generally responsible for coordinating the design of all disciplines (Burr & Jones, 2010). In some delivery methods (such as design-build), it is also common for construction to start before the completion of all the design documents; this is called a fast-track approach. In this case, construction drawings are sent to the field as they are finalized and as needed by the construction crew.

In the field, the superintendent along with other members of the construction personnel make use of the construction drawings to build. They are also responsible for reviewing construction documents and drawings before construction to verify any possible issues. In the case of any constructability problems or unclear information, the professional in the field contacts the design team to inquire and receive clarification. The construction industry depends on these information exchanges between professionals and companies. The effectiveness of design conception, development, and pre-construction services relies almost exclusively on feedback generated by site personnel. This need for efficient information flow is also essential during all building life within the AECO industry (Dave & Koskela, 2009) and all stakeholders (Emmitt & Gorse, 2003; Mohammed & Dumville, 2001).

Research on communication during the design phase is well established (Chiu, 2002; Sancar, 1996; Sonnenwald, 1996). During this phase, designers communicate among themselves and use their past experience and knowledge to conceptualize and develop new designs (Sonnenwald, 1996). The recent increase in complexity of designs also augments the number of participants involved in the design process with multiple specialty subcontractors, just as it would during construction. These professionals are from a wide range of disciplines and come "...with pre-existing patterns of work activities, specialized work languages, and different expectations and perceptions of quality and success, and different organizational constraints and priorities. Design participants need to explore and integrate these differences" (Sonnenwald, 1996, p. 279).

In the design phase, each designer should perform a task related to his or her field of expertise, but in doing so they will influence the design of others (Chiu, 2002; Kvan, 2000). This process may create problems for other designers, who then must communicate and collaborate to solve problems related to these issues. Iterations of design revisions are performed until the designers reach a consensus. This often corresponds to a cyclic design process (Chiu, 2002; Girard & Robin, 2006).

Many researchers who have studied collaboration and communication in design teams (Chiu, 2002; Kleinsmann & Valkenburg, 2008; Sonnenwald, 1996) argue that better communication among stakeholders can improve the effectiveness of the design process in the AECO industry. Other researchers (Kvan, 2000; Perry & Sanderson, 1998) have focused their research on the improvement of information and communication technologies (ICT) used for collaboration. The reason behind the improvement of ICT is also to provide improvement in communication between stakeholders in the construction industry.

Once the design is ready for construction, it is sent to the field. Then, another range of professionals, the construction crew, are added to the process. If the design documentation is sent to them without clear specifications or with conflicting issues, the construction team may send the design team a form called Request for Information (RFI). The RFI "...is a formalized process by which additional information can be clarified or obtained" (Mohammed & Dumville, 2001, p. 35). Nowadays, this process is usually performed electronically (N. Y. Cheng, 2003). Time spent in the process of RFI emission and response does not add value to construction because it consists of time waiting for information. Once an RFI is analyzed and it is determined that a change in the scope of work is needed, a document called 'Change Order' (CO) is emitted. O'Brien (1998) defines change order as:

> ...a formal change to the construction contract that usually includes a change in work scope (usually an increase; however, a decrease is also possible). With a change in work scope, there is usually an increase in cost (again, a decrease is also possible). Also with a change in scope, there can be a change in the time to perform the work (O'Brien, 1998, p. 1).

Stone, Johnson, and Leopard (2011) indicate that there are three main reasons why a change order is filed: (1) a change in the project originated by the owner; (2) a change in the process due to constructability issues; and (3) problems in design.

British reports indicate that 50% of errors found in construction are related to design (Love & Li, 2000). These were mainly due to problems in design coordination and documentation. Since that research was performed, significant pressure for process improvement in construction has developed (Dave & Koskela, 2009). Research has shown that the use of BIM may reduce design errors (Jeong, Eastman, Sacks, & Kaner, 2009), but these errors are still a concern for quality control within construction industry.

RFIs and COs are formalized documents in construction, which can also be referred to as explicit knowledge. As mentioned previously, tacit knowledge in construction plays a significant role, and research indicates that professionals and construction companies often use this type of information (Woo et al., 2004). Moreover, Barlow (2000) argues that "...project-based firms often have only patchy knowledge of their own portfolio of projects, relying on informal channels of communication between project groups as the principal source of information on their activities"(Barlow, 2000, p. 979).

Research about tacit knowledge in construction has been conducted in the realm of knowledge management (Dave & Koskela, 2009; Kanapeckiene et al., 2010; Lin et al., 2006; Woo et al., 2004). On the other hand, few studies about methods of informal communication used in construction have been identified, especially during the construction phase. Emmitt and Gorse (2003) published a book on construction communication in 2003. In this book, the authors (Emmitt & Gorse, 2003) broadly discuss the subject based on research conducted previously. Liu (2009) conducted a survey about communication in construction companies in China, but his focus was not on companies perceptions of efficiency per media channel but on overall communication between stakeholders. His study has shown that out of 21 factors analyzed which could influence communication effectiveness, the type of media used was ranked tenth in importance. Both Emmitt and Gorse (2003) and Liu (2009) found a low usage of internet based communication, such as email and video conferencing; this could have been influenced by availability of certain media during the moment when their research was conducted.

Liu (2009) also found that some of the problems of communication during the construction stage are: information underload (first in rank), inaccuracy (third), and misunderstanding (fifth), when he surveyed construction related companies in Beijing and Hong Kong. In relation to the choice of media channels used for construction related companies, Liu (2009) found considerable differences between Beijing and Hong Kong. In Beijing, the preferred four media of choice were telephone, meeting, face-to-face discussion, and fax, in that order; in Hong Kong, they were e-mail, telephone, meeting, and post, in this order. Liu (2009) acknowledges that these findings might be a result of some construction sites in Beijing not having access to email.

Even though recent technological changes have taken place, the research performed by Liu (2009) and Emmitt and Gorse (2003), which focused on communication of the construction phase as a whole (not specific to spatial and design issues), provided important data about construction communication. In the following subsection, an overview of significant communication theories is presented.

2.2 Communication Theories

In this dissertation, communication is defined as transfer of information between two or more individuals through the use of a medium. This is derived from Hofkirchner (2014), but with a stronger emphasis on the medium of communication, which here is also called the ‘channel’. The medium transmits symbols, which can be the language or signs (written or body signs) conveyed from one person to another; and communication represents a task consisting of expressing (by a communicator), and understanding (by the receiver) (Hofkirchner, 2014).

The problem of defining communication is a well-known issue for researchers in the field of communication (Cartier & Harwood, 1953; Dousa & Ibekwe-SanJuan, 2014; Newman, 1960). Cartier and Harwood (1953) indicate that there has been considerable discussion about this problem. As a result of their studies, they define communication as the "...process of conducting the attention of another person for the purpose of replicating memories" (Cartier & Harwood, 1953, p. 74). Newman (1960) indicates that this confusion is due to the broadness of what communication encompasses. This is why the definition provided by the author of this dissertation is a working definition, with the goal of clarifying issues bout communication. It is by no means an attempt to provide a final solution to this ongoing problem.

There are several theories or traditions within the field of communication. Craig and Zimring (2000) provide a comprehensive comparison between the seven most prominent traditions: rhetorical, semiotic, phenomenological, cybernetic, sociopsychological, sociocultural, and critical. He points out the main idea and most proeminent critics associated with each of them. In this dissertation, the focus will be drawn from semiotics, which defines communication as "... intersubjective mediation by signs" (Craig & Zimring, 2000, p. 133). This will then be supplemented with more specific media theories.

Semiotics studies how people use signs to communicate, either in expressing an issue or in making sense of information (Collinge & Harty, 2014). Emphasis is given to the decoder of the message. Craig and Zimring (2000) explain that miscommunication within semiotics is often understood as a difference in meaning that people might have for the same sign. This difference may be due to different backgrounds and life experiences (Fiske, 1990; Sun & Cheng, 2007; T. Wood, 2011). Thus, a common language becomes a prerequisite for effective communication (Fiske, 1990; Tindale, 2013). Nöth (2014) calls this collateral experience, based on the studies of Charles Pierce.

Research within this area also helps to explain that content might guide the choice of media for transmitting an idea (Craig & Zimring, 2000). By media, the researcher means the several channels available for people to transmit messages. Bolchini and Lu (2013) describe channel as "... simply what carries the message"(p.398).

Research indicates that media directly shapes the form of the final message. As Bolchini and Lu (2013) point out:

> Being forced to modulate our communication through a channel (even if we can choose one of many) implies the necessary consideration of the rules inherent to the channel (e.g. time, posture, style, genre, rapport with the receiver) and the adaptation of what we ideally would like to communicate to these constraints (p.398).

Therefore a persons' choice of media has the possibility of improving or reducing the capacity to effectively communicate a message. Further research on media helps to comprehend the impacts of this choice.

2.2.1 Media Richness Theory

Media richness theory (MRT) explicitly deals with how choice of media affects communication efficiency (Otondo, Van Scotter, Allen, & Palvia, 2008; Straus, 1997; Sun & Cheng, 2007). MRT was originated from studies conducted about organizations, such as the one by Trevino, Lengel, and Daft (1987). In this study, the researchers interviewed managers about their choice of media for organizational communication. Results were analyzed using three different types of reasoning: content (message clarity); symbolic (cues beyond the message content); and situation (other reasons). Trevino et al. (1987) showed that there was conscious reasoning behind the selection of media, stating that "Each medium has capacity for certain types of messages, is appropriate for situational constraints, and conveys symbolic cues" (Trevino et al., 1987, p. 572).

Effective communication within media richness theory is important because it reduces ambiguity and uncertainty, improving efficiency of transmitting information (Kishi, 2008; Sun & Cheng, 2007). Ranks for media richness have been developed by researchers to try to classify channels that might be seen as richer than others. These ranks are based on the possibility of immediate feedback, multiple cues, language variety, and personal focus (Daft et al., 1987; Straus, 1997; Sun & Cheng, 2007). Under these conditions, Daft et al. (1987) have developed the following rank, with number one as the richest media:

1. Face-to-face;
2. Telephone;
3. Written and addressed documents;

4. Written and unaddressed documents.

Straus (1997) indicates that computer mediated communication is often seen as "...information poor, or 'lean' as it restricts the exchange of nonverbal, para-verbal, and many status and interpersonal cues, and it eliminates information about participants physical surroundings (p. 233). Also, research indicates that as content complexity increases there is a need for communication to happen through a richer medium in order to obtain more information and reach a decision between stakeholders (Sun & Cheng, 2007). However, it is important to note that research on communication also shows that too much information or too many cues can cause overload in the receiver and reduce the message comprehension (Otondo et al., 2008).

To better understand choice of communication media, MRT shows that the sender's choice has impact over how the information is transmitted and on how it is perceived by the receiver. To add to this, semiotics indicates that there is a need for common ground so that the message will be received and understood in an effective way.

Even though Media Richness Theory is well developed in organizational setting research, little research explores how it affects the transmission of spatial information. More specifically, Fox et al. (2010) indicate a recent growing interest of the AECO industry in communication studies. The researchers (Fox et al., 2010) have conducted a quasi-experiment using three groups of four people. In this activity, the participants were asked to perform a design task, to which the input information varied in media (an image projection, a computer, or drawings). All groups worked in a face-to-face setting. Fox et al. (2010) found that media synchronicity (when feedback is immediate) is important for communication within construction. Nesan (2012) also indicates that quality of stakeholder communication is linked with the final project performance. Both studies suggest that further research may be necessary to comprehend how communication influences the construction process and to discover ways of improving communication effectiveness between stakeholders in the AECO industry.

2.3 Mental Models

As noted in the study in semiotics, a shared understanding is necessary for effective communication. Mental models are internal representations people use to help them make sense of the world (Johnson-Laird, 2006; Jones et al., 2011; Rouse, Cannon-Bowers, & Salas, 1992) and are an important part of how cognitive processes develop towards a shared understanding.

Jones et al. (2011) define mental models this way: "Mental models are conceived as a cognitive structure that forms the basis of reasoning, decision making, and, with the limitations also observed in the attitudes literature, behavior"(p. 1). Mental models are built upon life experiences, just as semiotics symbols perceived by different people differ in meaning due to past experiences.

Some characteristics of mental models are that they are partial representations of the real world (Johnson-Laird, 2010) and are highly adaptable, changing as we learn new things (Jones et al., 2011; Werhane et al., 2011). Werhane et al. (2011) suggest that mental models are derived from social constructivism theory. In this theory, the "...human mind organizes and orders its experiences, and that human knowledge is based on these constructions, as opposed to what may or may not exist apart from our experiences in the external world" (Werhane et al., 2011, p. 106). This explains how a lay person uses logic without formal training in the discipline in order to make an inference about daily life matters (Held, Knauff, & Vosgerau, 2006).

Some researchers speculate that mental models are formed by simplified visual representations (one or more images together), although others (Hegarty, 2004) argue that mental models with non-visual imagery are just as important. Held et al. (2006) indicate that mental models are similar to diagrams because they illustrate the structure of the thought or image that they represent. This simplification happens because of our cognitive limitations in replicating all aspects and details of a situation. Besides, the mental reproduction of too many details is not desirable if we will only use some of the aspects for our reasoning (Jones et al., 2011). This is easily explained with the example of solving a physics problem. This problem will focus on a moving person, and the goal of the exercise is to know precisely how long a person takes to move from one place to another. Notice that for this problem it was not necessary to describe the persons gender, color of hair, eyes, how tall they are, what clothes they are wearing, or other characteristics. The model is simple enough so that it can be used for reasoning, but it does not overload the solver with too many meaningless details.

The first mention of mental models was made by Kenneth Craik around the middle of the twentieth century. The notion of mental models has evolved considerably since then, especially with Johnson-Laird's studies, during the 1980s in which he explains that the model is used for reasoning and acts in a persons' working memory. Another important step was taken by Collins and Gentner, also in the 1980s, who revealed how the mental model is developed by using analogical thinking (Jones et al., 2011). The place for storing mental models, if in the working memory or the long-term memory, has been a discussion in the field over some decades (Jones et al., 2011; Vandierendonck, Dierckx, & Van der Beken, 2006) and does not fall within the scope of this work.

Mental models are an important cognitive tool for reasoning (Johnson-Laird, 2006; Jones et al., 2011; Werhane et al., 2011) and are described here as an introduction to problem-solving strategies. Johnson-Laird (2010) explains how this mechanism is supposed to work. He indicates that mental models serve as a basis for comparison through which we analyze possible outcomes of a given situation, assessing the need for, the possibility of, or probability of something happening. The more comparisons a person has to make at the same time, the more mental models need to be generated. When the number of mental models increases, complexity also tends to increase and inference is harder to make (Johnson-Laird, 2006).

Given the social constructivist approach to mental models, it is expected that they will be based on personal experiences that have been socially constructed (Werhane et al., 2011). This means that sometimes, due to the tendency one has to gather only information that does not contradict one's beliefs, one might not select all the needed variables to make a decision and therefore produce a misconception (Werhane et al., 2011) or confirmation bias, which is when "people seek information that fits their current understanding of the world" (Jones et al., 2011, p.5). The exchange of ideas is important for adjusting mental models in order to reduce misconceptions.

Different people might also work on mental models together, through a shared or team mental model. Shared mental models and team mental models are different concepts (Jones et al., 2011). Shared mental models are based on the collection of similar individual models from people in a group; team mental models are that of the group, where a group is treated as one entity.

> The notion of a shared mental model is distinct from that of a team mental model, in that the latter refers to shared cognition in a team as a collectivity, not shared cognition among dyads of individuals, which the alternative phase shared mental models does allow. (Langan-Fox et al., 2001, p.100)

Research on team mental models has proliferated in the field of organizational development. Within this area, team mental models are perceived as a useful concept for understanding teams' dynamics (Langan-Fox et al., 2001). This happens because teamwork has to be supported by shared understanding among individuals. Jones et al. (2011) indicate that in order for people with different views to work together "...it is necessary to identify and support a shared understanding among relevant stakeholders and to enhance the collective decision making process" (p.4). Other researchers in the field also support this view (Langan-Fox et al., 2001). In other words, team mental models help teams understand how they are structured in the face of a given task (Rouse et al., 1992). This helps them make sense of the conditions available and find the best available solutions in order to perform the job or solve an existing problem.

However, the team mental models used by a group also are prone to some problems. For example, if the team mental model is shared by all and there are no more individual contributions, then the group may face underutilization due to the lack of new input and ideas. As Klimoski and Mohammed (1994) put it: "...completely overlapping team mental models are viewed as dysfunctional with regard to team performance" (p.420). Because multidisciplinary team members often have very diverse backgrounds, a complete overlap of team mental models is highly unlikely in that situation. This is one of the reasons to use multidisciplinary teams.

The formation of a team mental model happens in the initial moments of a task, when team members are making sense of each other: "...there is a period of time when team members spend energy to elicit from and share with others how they wish to work together" (Klimoski & Mohammed, 1994, p. 423). This is the time when the team mental model starts to form. After this initial phase, conflicts may appear, and they are dealt with by adjusting the team mental model. Also the influx and outflux of team members may affect the team mental model development (Klimoski & Mohammed, 1994).

In all situations, information sharing plays an important role in improving the team mental model. Mohammed and Dumville (2001) indicate that research on information sharing and team communication helps elucidate the process behind how a team organizes itself. Based on research about team mental models, this can be understood as the development and refinement of team mental models. Once again, for teams to advance and improve their creativity, they need to have members who withhold shared information, as well as additional unique information that is not shared among all team members. This unshared information can help understand the problem from a broader range of perspectives, and therefore improve a teams' repertoire of ideas.

On the other hand, even though mental models have been studied over some decades, they are considered difficult to measure (Rouse et al., 1992). Langan-Fox et al. (2001) have attempted to measure team effectiveness based on team mental models using survey methods (questionnaire) and a pair-wise rating task. Klimoski and Mohammed (1994) also mention other techniques for measuring aspects of mental models, such as protocol analysis, analytical modeling, and experimentation. However, because of its existence only as an abstraction inside people's minds, representation and measurement is subject to each person's interpretation and bias.

2.4 Problem Solving

Problem solving and critical thinking skills are seen as complementary to technological development (Green & Jax, 2011; Saavedra & Saavedra, 2011). They also have been indicated as crucial to the future of education in the United States (International Technology Education Association, 2007, 2002, 2000; National Research Council, 2012). Researchers in the construction industry also found that these skills are essential to work in their field. Chan and Sher (2014) mention that studies conducted with AECO companies indicate skills in "...communication and negotiation, teamworking and inter-disciplinary working, planning, decision making and problem solving as highly important" (p.533).

To be more precise, some researchers (Ball, Evans, & Dennis, 1994; Newell & Simon, 1972; H. A. Simon, 1973) even consider design as a type of problem-solving activity. Others disagree with reducing the process of design to just a problem solving task (Visser, 2009). The focus of this research is design problems during the construction phase. In this case, the researcher uses the definition of

Stempfle and Badke-Schaub (2002) that designing is a sub-area of problem solving. This dissertation will not discuss creativity issues in design.

Problem solving in design focuses on ill-defined problems as opposed to well-defined problems. Ill-defined problems require the solver to spend time understanding and framing the problem and they may have multiple solutions (Ball et al., 1994; Dorst & Cross, 2001). Well-defined problems usually have only one end solution and a known process to achieve that solution (Jonassen, 1997; Schraw, Dunkle, & Bendixen, 1995).

Ill-defined problems require a higher level of thinking than well-defined ones, especially the activation of the so-called epistemic monitoring. The latter refers to "...the legitimacy of solutions rather than the processes used to reach a solution" (Schraw et al., 1995, p. 524). Therefore, different processes are necessary for solving well-defined and ill-defined problems.

According to researchers Dorst and Cross (2001) and Stempfle and Badke-Schaub (2002), the problem solving task within design consists of aligning the goal space with the solution space. The goal space is limited by the constraints of the project while in the solution space all possible solutions are available. Stempfle and Badke-Schaub (2002) hypothesized that, in order to reach a final solution, designers go through four stages of cognitive operations: generation, exploration, comparison, and selection. These operations can be further broken down under content and processes analysis, providing more information about the processes that solvers use while dealing with a design problem-solving task.

The goal space for design problems in the construction phase is much smaller than during the design phase. This is mainly due to the addition of constraints related to constructability and time management beyond all the design constraints imposed during the previous phases. Thomson, Austin, Root, Thorpe, and Hammond (2006) indicate that the cost and difficulty of project change is greater during the construction than during the design phase, while the added value of change is smaller during construction than if done before (during the design phase).

In the present study, the researcher will focus on the construction phase, during which solvers must deal with more constraints during their problem-solving activity.

Stempfle and Badke-Schaub (2002) conducted a study on team communication during a design problem-solving task. In their study they classified group interactions as content or process and analyzed the strategies communicated within each, as presented in table 2.1. They also considered the existence of residual communication within groups while performing the task.

Table 2.1
Team strategies for problem-solving task (Stempfle & Badke-Schaub, 2002)

Content	Process
Goal clarification	Planning
Solution generation	Analysis
Analysis	Evaluation
Evaluation	Decision
Decision	Control
Control	

Stempfle and Badke-Schaub (2002) found in their study that individuals tend to analyze and evaluate single solutions before moving to others in order to reduce the cognitive load. While analyzing groups of participants with various levels of understanding, Stempfle and Badke-Schaub (2002) found that solvers emphasized the analysis of the proposed solutions phase. This phase encompassed group questioning about the solution space. With a more thorough analysis of the problem, the researchers indicated that iterations done in order to improve shared understanding might contribute to the fact that heterogeneous groups outperformed groups of people that were more homogeneous. In heterogeneous groups, more iterations were necessary to achieve shared understanding.

Teamwork and multidisciplinarity have grown in importance since the late 1990s (Denton, 1997). These concepts have been shown to improve work effectiveness, although sometimes they are not appreciated by all workers (Denton, 1997). Teamwork and multidisciplinarity can also be challenging for communication because of the specific languages each field uses (Kleinsmann & Valkenburg, 2008; Sonnenwald, 1996). Overall, though, teamwork is beneficial to problem-solving tasks because "At the most basic level, teamwork brings several minds to bear on a problem. These can act to cancel errors that any individual may make..." (Denton, 1997, p. 158).

Teams with different backgrounds are important for the design process. They are seen as a way of improving the creative process, since creative input can come from different areas (Denton, 1997; Sonnenwald, 1996). Sonnenwald (1996) used observation of behavior and communication in groups to determine roles that support and do not support collaboration among team members. Based on her study, Sonnenwald (1996) identified several roles for design collaboration, many of which are responsible for monitoring and ensuring project goals as well as coordinating stakeholders within and between groups. Some of the roles enhanced by multidisciplinary work are:

- Interorganizational star: articulates the project to other departments and organizations to make sure it is coherent with their needs;
- Intergroup star: coordinates interactions between different teams;
- Intragroup star: coordinates interactions between members of a team;
- Intertask star: responsible for discussing tasks between different teams;
- Intratask star: organizes task and deals with conflicts within groups;
- Interdisciplinary star: people that work across disciplines with the aim to "...create new knowledge and solve design problems" (Sonnenwald, 1996, p. 292);

- Interpersonal star: acts as a communication facilitator within a team;
- Agent: act as coordinator and facilitator among all involved in a design project.

According to Sonnenwald (1996), one person can assume more than one role during the design project. She also noticed that some roles require a greater amount of professional experience. This suggests that while some of the roles might need skills developed through formal education, others need expertise gained through professional practice (Sonnenwald, 1996).

Sonnenwald (1995) also mentions that communication between team members is of "...paramount importance to design outcomes"(p.860). Chiu (2002) indicates that "The effectiveness of design communication becomes critical for designers in sharing design information, in decision-making and coordinating tasks"(p. 187). In all phases of design, communication between team members is important in order to provide feedback and result in adjustment of the problem solving space (Stempfle & Badke-Schaub, 2002).

Therefore, the concepts of teamwork and the formation of team mental models derive from the same idea of developing a shared understanding. Communication among team members is essential for the improvement of the team mental model and, as a result, reasoning about the problem to be solved is improved. In the next section, the influence of expert and novice differences on problem solving will be discussed.

2.4.1 Novices and Experts

Literature on novice and expert differences in problem solving is well established (Bryson, Bereiter, Scardamalia, & Joram, 1991; Chi, Glaser, & Rees, 1982). Most studies conducted focused on understanding the different processes by which reasoning happens in experts and novices. Results have shown that experts group information differently than novices and that "...the expert in several diverse domains is able to remember 'sequence of moves' much more rapidly than the novice" (Chi et al., 1982, p. 10).

Expertise in a trait is the result of mastery through building a repertoire of cases. This is clear when analyzing chess masters. A well-known experiment performed by de Groot compared chess grand masters and novices regarding their thought processes on chess movements and positions (Bilalić, McLeod, & Gobet, 2008). Chi et al. (1982) indicate that this might be due to the amount of time chess masters dedicated to playing, therefore building a database of moves and sequences.

Chase and Simon (1973) have reproduced de Groot's experiment, analyzing more specifically how experts and novices differ when agglomerating information. This agglomeration is also called 'chunking.' They have found that there is a significant difference in expert and novice recall of how the pieces are positioned on the board only when these positions are not random. This is compatible with the idea that the chunks experts use to conglomerate information can be connected by "...relations of mutual defense, proximity, attack over small distances, and common color and type" (Chase & Simon, 1973, p. 80), although they also indicate that other abstract relations and hierarchies may be used by experts to organize pieces into chunks.

Another characteristic of expertise is that it is domain specific (Lesgold & Lajoie, 1991; Pollock, 2000; Richbart & Richbart, 2014), though the process of chunking information into bigger pieces and arranging it in a rational hierarchy seems to be repeated over different disciplines (Akin, 1980; Egan & Schwartz, 1979; Lesgold & Lajoie, 1991; Pollock, 2000). This relates to learning theories in which the main goal is to turn novices into experts. Understanding chunking and the differences in thought processes of experts and novices may help develop methods to improve learning.

Another difference between experts and novices is in the use of problem-solving strategies. D. P. Simon and Simon (1978) have found that while experts use a forward approach to problem solving, taking advantage of the information stated in the problem, novices use a backward approach. In other words, novices start from the end goal, choose a method that will result in the variable that they need, and then find the information in the problem statement that can be used in the method (Bryson et al., 1991; Pollock, 2000; Richbart & Richbart, 2014; D. P. Simon & Simon, 1978). On the other hand, since experts have acquired a greater repertoire of experiences, they know which variables are important and which methods to choose from in order to move forward (Bryson et al., 1991).

Pollock (2000) indicates that, based on previous research, experts encounter similar problems and, therefore, do not need "...to go through the general search processes novices rely on to solve problems" (p. 78). Therefore, results are faster and less prone to errors. Also, Nokes-Malach, Meade, and Morrow (2012) indicate that expertise similarity in a group setting should improve collaboration. This is mainly due to the fact that experts tend to focus more on critical aspects of a task and that cues may be easily communicated from one peer to other in order to trigger collaboration (Nokes-Malach et al., 2012).

Expert and novice differences contribute to the development of problem solving as a concept. How individuals and groups progress towards expertise is an essential part of cognitive psychology and education. The following two concepts are also important for understanding team dynamics in problem solving: metacognition and epistemic beliefs.

2.4.2 Metacognition and Epistemic Beliefs

In real world settings, ill-defined problems exist in greater quantity than well-defined problems. Because ill-defined problems are not bound to have only one right solution, it is important for solvers to consider many alternative solutions prior to making a decision. Some researchers indicate that due to this property, the solving of an ill-defined problem is similar to a design process (Jonassen, 1997).

Metacognition plays an important role in rationalizing about ill-defined or design problems. Hofer and Sinatra (2009) indicate that no consistent definition of the term has been noted in literature, though the most frequent description is ‘knowing about knowing,’ or what a person understands about his own learning process. Some examples of metacognitive processes are: “...awareness of how one learns, the ability to judge the difficulty of a task, the monitoring of understanding, the use of information to achieve a goal, and the assessment of learning progress” (Jonassen, 2000, p. 70).

Metacognition in problem solving helps solvers question what they know about the subject and what they need to know about it in order to progress through the problem-solving process (Jonassen, 1997). Because it is an internal process that involves recognizing when one does not have enough information, the solver must use techniques of questioning and inquiry.

After gathering enough evidence and producing alternate solutions, the solver must analyze and compare the alternatives. In this point, the so-called epistemic beliefs are processed. Epistemic beliefs are related to epistemic strategy, defined as “...knowledge-based validation and consistency checking approaches employed in learning tasks” (Hofer & Sinatra, 2009, p. 114). Hofer and Pintrich (1997) describe epistemic beliefs under two main categories: the knowing and the knowledge. Both are further separated into certainty and simplicity (of knowledge), source of knowledge, and justification for knowing. Their evaluation is complex and, for this dissertation, epistemic beliefs will be considered as “...standards for the evaluation of information that is to be learned” (Hofer & Sinatra, 2009, p. 115).

Validity of information is an important issue to be analyzed when considering design options or alternative solutions in problem solving (Jonassen, 1997, 2000; Schraw et al., 1995). Beliefs are also part of the process in which individuals rationalize with their mental models to identify possible inaccuracies or errors in judgment that must be reevaluated individually or with other members of the group.

Koole (2012) argues that epistemics is seen by some researchers as a social and interactional phenomenon because it requires participants in a social setting to understand how they should organize information received from the conversation, evaluating whether certain information seems to be more valuable or correct than other information. Koole (2012) also indicates that epistemic beliefs in a social setting help explain how a person chooses another person to ask a question. In a multidisciplinary industry such as AECO, this knowledge is an important asset for effective teamwork.

2.4.3 Gender and Personality Influence on Problem-Solving

Problem-solving tasks can also be influenced by the gender and personality of problem-solvers. Research on gender has showed that females are more concerned with interpersonal relations than males (Strough, Berg, & Meegan, 2001), have different approaches to communication (Brink-Muinen, Dulmen, Messerli-Rohrbach, & Bensing, 2002), and tend to reflect more before acting (Kimbell & Stables, 2007).

Research performed by Strough et al. (2001) in an eighth-grade environment showed girls to be more worried about the social balance within the group than boys. Male students tended to focus first on individual interests and only afterward on group solidarity. Their research also showed women to outperform male students in collaborative tasks. This is compatible with research performed by other researchers, such as W. Wood (1987) and Hyde (1981).

Other researchers in gender differences have reported that males and females have different approaches during problem-solving tasks. Kimbell and Stables (2007) performed extensive research on gender differences and indicates that when performing a collaborative problem-solving task, female students tended to reflect more while male students took a more active approach. By reflective tasks, Kimbell and Stables (2007) meant defining tasks and evaluating ideas; active tasks, on the other hand, involved idea generation and development.

Differences in communication patterns and spatial visualization skills between men and women are also important. In communication research, Adrianson (2001) has studied gender differences in computer-mediated communication. In his literature review, Adrianson (2001) indicates that the communication pattern differences between men and women is derived from the differences in social behaviour. Again, women were seen as more socially oriented and men more individualistic. This means that females would change their opinions more often in order to reduce conflict. This confirms the idea that females are more socially oriented (Strough et al., 2001). Research performed by Adrianson (2001) has shown this trait in female behavior, especially when using computer mediated communication (CMC). However, male dominance in face-to-face interaction was not confirmed by that same study (Adrianson, 2001).

Gender differences in spatial perception is also well studied in previous research. Voyer, Voyer, and Bryden (1995) have revisited several spatial ability studies and identified that gender differences do occur, normally to favor males. They also indicate that this difference tends to grow with increasing age. Also, gender differences vary by spatial ability, with mental rotations being the ability with greatest gender differences, followed by spatial perception and finally spatial visualizations. In the latter, almost no differences were observed (Rilea, 2008; Voyer et al., 1995). Explanations for these differences are vast, ranging from hormonal differences and cerebral lateralization to differential experiences and socialization (Rilea, 2008; Voyer et al., 1995).

Beyond the differences mentioned before, the issue of gender inequality within the construction industry is also notable. Research conducted in Sweden (Styhre, 2011), Palestine (Enshassi, Ihsen, & Al Hallaq, 2008), and the United Kingdom (Gale, 1994; Worrall, Harris, Stewart, Thomas, & McDermott, 2010) shows that women are under-represented in the industry. In the United States, an Occupational Safety and Health Administration (OSHA) report revealed the construction workplace to be a hostile environment: "... The construction industry has been overwhelmingly male dominated for years, and on many job-sites women construction workers are not welcome" (Health and Safety of Women in Construction workgroup & Advisory Committee on Construction Safety and Health, 1999). Even though the OSHA report is more than a decade old, a more recent report by the United States Department of Labor still indicates that women account for only 12% of construction workers (US Bureau of Labor Statistics, 2014).

Reasons for this unbalance are many. The most recurrent reasons found in literature include discrimination from within industry workers and long work hours (Styhre, 2011; Worrall et al., 2010). In this case, construction is seen as a masculine and paternalist industry. Styhre (2011) provides examples of research performed in the United Kingdom, Australia, and the United States, where a sexist view is evident in varying degrees. All of these studies confirm the view that the construction industry is a male dominant industry.

Finally, problem solving is a vast area of research that receives contributions from several fields such as psychology, education, and sociology. Acknowledging these factors informs the reader about limitations and delimitations of this study.

2.5 Methods

In this subsection, the researcher will provide background information about the methods chosen for the study. The overall methodology used in this dissertation is mixed methods. Researchers indicate that this method is not just a combination of quantitative and qualitative data, but an effort to produce a stronger findings than quantitative and qualitative methods could produce independently (Creswell, 1994; Mertens & Hesse-Biber, 2013). Greene (2012) indicates that:

> When appropriate, a mixed-methods approach can contribute importantly to the quality and reach of a study specifically through its respectful engagement with multiple ways of knowing and multiple

> perspectives on the character of human phenomena and the prerequisites for warranted knowledge (pp.55-56).

The use of mixed methods is not new, but interest in it has been growing since the early 2000s. Mertens and Hesse-Biber (2013) indicate the foundation of the Journal of Mixed Methods Research in 2007 as a proof of this growing interest. This journal has grown in importance, reaching an impact factor of over two in 2007 (Mertens & Hesse-Biber, 2013), and 2.186 in 2014 (Journal of Mixed Methods Research, 2016).

In this dissertation, the researcher will use a sequential mixed methods approach. In this approach, data from one phase will be used in the development of the following phases. This reuse of data has the goal of deepening and expanding the results found in previous phases (Bazeley, 2011; Creswell, 1994; Guest, 2012).

In this study, the first phase will consist of an online questionnaire, the second of interviews, and the third of a quasi-experiment. A questionnaire is defined by Sekaran and Bougie (2010) as "...a preformulated set of questions to which respondents record their answers, usually within rather closely defined alternatives"(p. 197). The use of a questionnaire is a good fit for well-defined variables (Sekaran & Bougie, 2010).

Electronically distributed questionnaires have advantages and disadvantages. Some of the advantages are that they can be distributed over a large geographical area and be completed at a convenient time for the respondents (Gall, Gall, & Borg, 2007; Sekaran & Bougie, 2010). The disadvantages are a low response rate, the impossibility of clarifying doubts that may arise during its completion, and a possible sample bias due to the low response rate. Some strategies described to improve return rates are to send respondents reminders and present the respondents with information about the study (Gall et al., 2007; Sekaran & Bougie, 2010).

In order to provide valid research data, questionnaires must be designed adequately (Brace, 2008). Sekaran and Bougie (2010) indicate three main areas of concern for researchers while designing a questionnaire: wording of questions, planning for response analysis, and general appearance. When designed properly, questionnaires allow the researcher to reach a great number of people, which may yield large quantities of data that can be fairly easy to code and analyze (if properly prepared for).

Phase two of this study uses interview methods. The interview is a way of providing more qualitative information about the findings in the questionnaires. Sekaran and Bougie (2010) indicate this method as a good way of obtaining information in exploratory studies. Other researchers (Gall et al., 2007) indicate that another advantage of interviews is that they are easy to adapt. Even though useful for further clarifications, interviews must be conducted carefully in order to reduce interviewer bias. Interviewer bias happens when actions from the interviewer influences interviewees' responses (Gall et al., 2007; Sekaran & Bougie, 2010).

There are three main types of interviews: structured, semi-structured, and unstructured. The researcher using a structured interview has a clear view of the goals of the questions, which are the same for all respondents and are asked in the same order. In a semi-structured interview, the researcher has initial questions, but additional ones can be added as the interview evolves. The follow-up questions are based on answers the interviewees provide. In the unstructured interview, the researcher does not have guidelines, asking questions as conversation evolves and probing the respondent to discuss issues of interest (Gall et al., 2007; Sekaran & Bougie, 2010).

Interviews are useful for gaining more in-depth information about the issue that is being researched (Sekaran & Bougie, 2010). Some setbacks of the interview method are that interviews are hard to code and analyze, and complete anonymity for the interviewee is difficult (Gall et al., 2007).

Sekaran and Bougie (2010) indicate three ways interviews can be conducted: face-to-face, telephone, and computer-assisted. Face-to-face is still the most frequently used method (Deakin & Wakefield, 2014). Its advantage is that face-to-face provides social cues that interviewers can interpret and use in the report. These social cues also provide information that is useful for developing new questions in the case of semi-structured and unstructured interviews. The disadvantage of face-to-face are that it is an expensive method, and the researcher might be limited to interviewing a smaller sample (Brace, 2008; Gall et al., 2007; Sekaran & Bougie, 2010).

Telephone and computer-mediated interviews are cheaper and could be used to gather data from a more geographically dispersed sample. These two methods also facilitate anonymity of interviewees. The setbacks in using telephone and computer-mediated interviews are that social cues over the telephone are limited, and through computer they are even more restricted. Brace (2008) also notes that it is harder to show visual material to interviewees when performing telephone interviews. It is possible to have the materials sent previously to respondents, but this also increases cost and overall time of the process.

Nowadays, new internet communication media is available, such as media based on voice over the internet protocol (VOIP). Little research has been done on using VOIP for research purposes (Deakin & Wakefield, 2014). Examples of applications that use this are Skype and Google Hangouts. Weinmann, Thomas, Brilmayer, Heinrich, and Radon (2012) have studied this method as an alternative channel for conducting interviews. Their sample contained 300 people ranging from 18 to 24 years old. The findings show that the use of VOIP poses some usability issues, such as the fact that interviewees must have the software installed in their computers. Deakin and Wakefield (2014) reported some advantages in the use of VOIP interviewing. They are: more flexibility for the interviewer, cost and time effectiveness, and the possibility of establishing good rapport with the interviewee. The reported setbacks mentioned by Deakin and Wakefield (2014) are that some participants may decline the interview because they do not know how to operate the software or a computer, and technological issues may become a concern where bandwidth is unstable. A more complete description of advantages and disadvantages of using Internet-based video conferencing technologies for interview purposes can be found in Deakin and Wakefield (2014).

The final phase for this dissertation will include a quasi-experiment. This activity will be performed to obtain more input on the communication strategies used to solve a design problem. A quasi-experiment is an experiment in which subjects are not randomly assigned to groups (Cook & Campbell, 1979). It is known to researchers that randomly assigning subjects is almost impossible in field studies (Ellis, 1999; Gall et al., 2007). A quasi-experiment result is seen as weaker than true experimental results (Sekaran & Bougie, 2010), but "If carefully designed, yields useful knowledge" (Gall et al., 2007, p. 416).

2.6 Summary

In this chapter the researcher gathered previous relevant literature about concepts to help in the comprehension of the studied phenomena. First, the author provided an overview of the AECO industry and about communication within that industry. Literature pertaining to communication in the AECO industry indicated a gap in the research about field personnel and design team communications regarding design problems.

The communication issues and theories presented, especially Media Richness Theory (MRT), argue that the channel of transmission affects the overall message comprehension. MRT also indicates how choices of media are made based on the ability of the channel to transfer different types of cues. Face-to-face is the richest media because it provides social cues beyond the verbal message. The level of richness decreases when using the telephone, and it decreases further with email or fax.

Following communication issues, the reader was presented with the concept of mental models. These are individual, simplified, and partial representations of reality used for reasoning. When people interact with others, such as when they argue in order to obtain a group decision, they are adjusting their individual mental models to a shared mental model. Mental models are important for problem solving because they help to explain how people reason and make inferences.

Design can be seen as a form of ill-defined problem solving. Critical thinking and problem solving are seen as desirable traits for students and workers in construction. However, differences exist between novices and experts in problem solving. It has been indicated in previous literature that experience in the field accounts for a better understanding of important variables and strategies to be considered.

Two other concepts related to problem solving are taken into account in this dissertation: metacognition and epistemic beliefs. While metacognition is the act of self-reflection in order to identify the elements already known about a problem and the ones that still need to be searched for, epistemic beliefs involve reflecting on the credentials and validity of sources used. The researcher also acknowledges the influence of gender and personality traits on problem solving.

Finally, an overview of literature regarding the methods chosen for this research was provided. The following chapter will provide more detailed information about how these specific methods are applied in this study. It will also discuss the process of data gathering and analysis.

CHAPTER 3. FRAMEWORK AND METHODOLOGY

In this chapter, the researcher provides an overview of the methodology for the study. First, the rationale and frameworks are presented, followed by the research questions, research design, population, sample, and instruments. At the end, before the chapter summary, the researcher describes how data collection and data analysis will be performed.

3.1 Rationale

As mentioned in chapter 2, the method chosen for this study is mixed methods with a sequential approach. This approach is used when one phase of the study provides input for better defining the next phase (Bazeley, 2011; Creswell, 1994; Guest, 2012). The choice was made to assure that data used in phases is updated with previous result findings. Phases previous to the quasi experiment are necessary in order to better define levels of the variables of interest.

The first phase provides quantitative input regarding the main media used for informal communication of spatial design issues between field and design personnel. Nevertheless, the researcher recognizes only a quantitative study alone does not provide in-depth information about common issues and strategies for overcoming constraints in the communication channels already in use in industry. This establishes a need for a second phase: qualitative input from industry professionals using interviews. The interviews provide more information about types of problems faced by professionals while using the main forms of communication found in phase one. This phase helps the researcher develop the case study for phase three, the quasi-experiment. This approach is similar to the one conducted by Gorse et al. (1999). In their paper, Gorse et al. (1999) researched the appropriate channel for problem solving in construction, also using a three-phased study consisting of questionnaire, semi-structured interviews, and then case studies. Their focus, however, was not on spatial design issues but on general problem solving in construction.

In this dissertation, after obtaining input from the first two phases, the communication of problem solving strategies is further analyzed through a quasi-experiment with a full factorial design. During the quasi-experiment, a case is presented to the participants and they have to solve the problem by communicating through the channels specified to them. As assessing expertise may require additional time by the researcher, this study will use experience as a variable. Therefore, it is assumed that expertise is directly connected to the level of experience one has in the construction industry. Strategies used by participants during the problem-solving task in the quasi-experiment are taken into consideration during the analysis. The quasi experiment allows the researcher to compare strategies used for each medium. This would not be possible if a case study approach was used because the researcher would be limited to analyzing the media in use by professionals.

The last phase uses quantitative data as well as qualitative data for its analysis. For qualitative input, the researcher reviewed video footage and transcripts of sessions in order to understand differences in strategies used by solvers for each channel. The last two phases of the study provide information about media usage and choice and strategies to overcome difficulties. This allows guidelines for effective communication about spatial problems to be produced - the final goal of this dissertation.

In the following sections, the researcher gives an overview of the theoretical and conceptual framework behind the rationale for this approach. The theoretical framework is derived from the concepts studied in the literature review. They are organized in a particular order that helps explain the reasons behind the dissertation's idea. The conceptual framework shows how these ideas are collected and used for data gathering and analysis throughout the phases of the study.

3.2 Theoretical Framework

The theoretical framework for this study draws from the findings reported in chapter 2 (Literature Review) of this dissertation. Three main concepts (Media Richness Theory [MRT], mental models, and problem solving) are used, with the AECO industry as the background. The researcher applies the following questions to the concepts used: who, what, how, and why? Table 3.1 provides the rationale for linking the background literature to these questions.

Table 3.1
Rationale for the use of concept and theories

Question	Rationale	Theory or area of study
Who?	Population	Construction Industry
What?	Idea to be communicated	Mental Models
How?	Way message is transmitted	Media Richness Theory
Why?	Reason for communicating	Problem Solving

The construction industry is the population of interest in this study. The background literature has provided information about some specific characteristics of this industry, such as its fragmentation (Chan & Sher, 2014; Dave & Koskela, 2009; Grilo et al., 2013) and resistance to the use of technological novelties, though the latter has been shown to have changed in recent years (Dave & Koskela, 2009).

The questions of 'What needs to be communicated' in this research framework is related to information exchanged between people. Chapter 2 has shown how mental models are tools for people to make sense of information and use it for making inferences and solving problems. Mental models can be refined through iterations to achieve shared understanding and therefore a shared mental model.

The way information is transmitted also affects the way it can be perceived by the recipient of the message. Media Richness Theory (MRT) indicates that certain media, such as face-to-face communication, provide more non-verbal cues that can help the understanding of the message.

Finally, the goal of this dissertation is to improve communication between construction site personnel and design professionals in solving design problems related to space. Literature indicates several points that help the researcher understand the processes that individuals and teams use to solve a problem. One of the main ideas is the difference in expertise and novice problem solving. In this study, professionals from the construction industry will represent industry expertise, while students will represent novice knowledge about the subject.

Figure 3.1 summarizes the theoretical framework model for this dissertation. It visually reflects how theories and concepts drawn from the literature review connect to inform the reader and the researcher how to approach the research process.

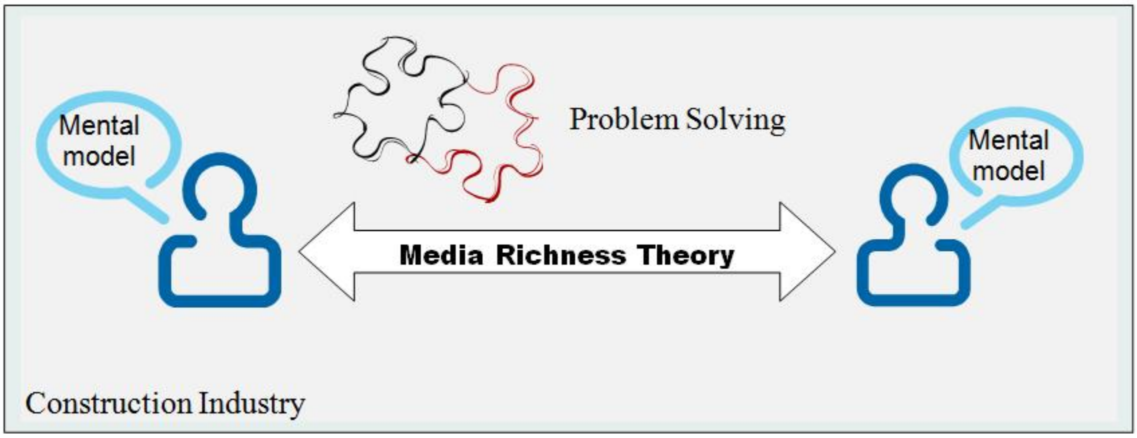
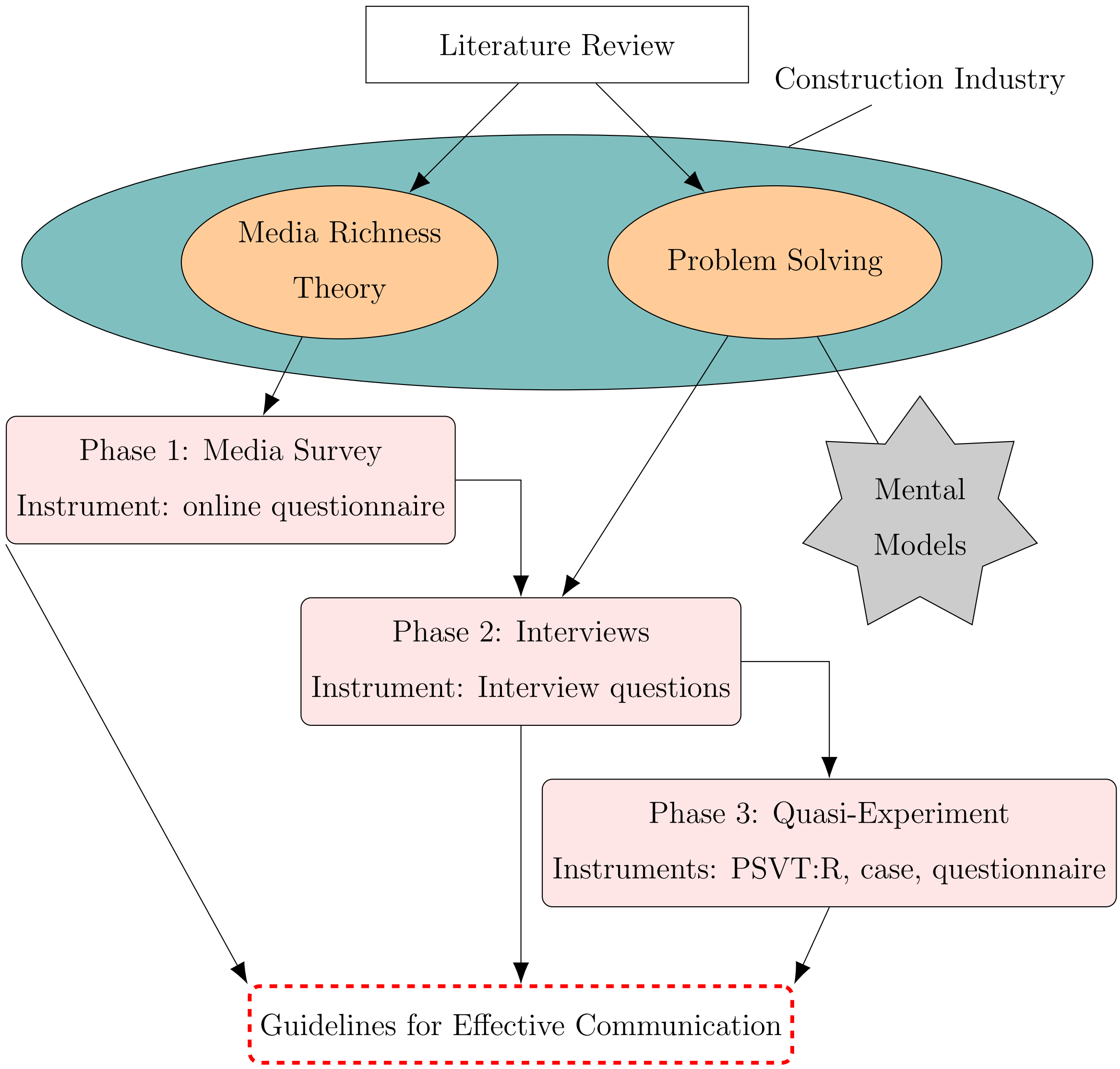


Figure 3.1. Concept map for the theoretical framework of the dissertation

3.3 Conceptual Framework

The conceptual framework for this study explains how theories and concepts presented in Chapter 2 (Literature Review) are used to inform data gathering and analysis in this dissertation. In the conceptual framework, the inputs and products for each phase of the study are indicated. Figure 3.2 illustrates how the work is structured for this dissertation.

Figure 3.2. Inputs and outputs per phase of the study



Mental models will be used to inform about difficulties that may occur during the problem solving process. The researcher is especially interested in communication issues that may result from differing mental models. Also, mental models help inform how people with different backgrounds may approach problems differently and how they may adjust their models through iterative communication.

Table 3.2
Inputs and outputs per phase of the study

Phase	Inputs	Outputs
Phase 1: Survey	Literature review	Main channels for informal communication in construction industry (field and design personnel)
Phase 2: Interviews	Literature review & Phase 1 outputs	Major advantages and disadvantages for each communication channel
Phase 3: Quasi-experiment	Literature review & Phase 2 outputs	Different strategies used for communication and problem solving
General	Literature Review & Phase 1 outputs & Phase 2 outputs & Phase 3 outputs	Guidelines for effective informal communication in construction industry between field and design personnel

Also, even though figure 3.2 shows no links back to the literature review, a review of background literature to update references will be performed after each phase before discussing partial results. This iterative process allows the researcher to better understand the results and therefore provide a more thorough analysis of the findings. Table 3.2 presents the inputs and outputs for each of the three phases of this mixed methods-research approach.

The final goal for this dissertation is to provide guidelines for effective communication in the construction industry, especially relating to informal communication between field and design personnel. After the performance of data analysis and a review of pertinent literature, each phase will expand on the previous one. At the end, it is expected that all phases will contribute to the establishment of the guidelines. These guidelines could be used for students or workers who seek to improve their communication skills pertaining to spatial problems in the construction industry.

3.4 Research Questions

Research questions for this study are:

1. How does the choice of media influence problem reporting and problem solving between field and design teams?
   (a) Which are the main media of communication between site and design teams when reporting spatial problems related to design?
   (b) What are the advantages and disadvantages of each of the most used media?
   (c) What are the perceptions of effectiveness, difficulties, and strategies, students and professionals of construction related fields experience while using each of the main media of communication?

Question 1.a is answered with the analysis of data from phase one. Question 1.b is answered from data obtained from phases one and two, and question 1.c is answered using outcomes and data from phase three.

3.5 Research Design

As mentioned before in this chapter, this study uses a sequential mixed-methods approach. The first phase is comprised of an online questionnaire; the second, of interviews; and the last, of a quasi-experiment.

The first questionnaire was submitted to industry professionals. This phase yields the three main channels used in construction to communicate informally between field and design personnel about spatial issues. The questionnaire also obtained demographic data from the respondents. Six different types of media channels were rated using a ranking scale and a five-point Likert type scale. Media channels selected for the questionnaire were based on background literature. A Likert scale was also used in part of the questionnaire developed by Liu (2009) and Gorse et al. (1999) to evaluate channels of communication during the construction phase in AECO companies in China.

Based on the findings from the online survey, the researcher has adjusted the questions previously developed for the second phase interviews. In the second phase interviews, industry professionals were asked about frequent problems they encounter while using the three main media used for informal construction communication. A similar approach was chosen by Gorse et al. (1999). Qualitative information collected in phase two helped to develop a case for phase three.

The researcher used a quasi-experiment for phase three of this study. During the experiment, volunteers worked in groups of two in order to solve a design problem. One person played the role of the site engineer and another took on the role of the design manager. Specific background in construction and or design was necessary for the roles (either academic, for students, or professional, for industry professionals). The intention was to reproduce some of the fragmentation that exists in construction.

Volunteers in phase three had varying levels of experience in construction and also have used different channels of communication. Both experience and channels are variables in this study. Specific communication channels to be used in the experiment were assigned to groups at the time of the activity. Participants were asked to come to a one-hour meeting during which they took a spatial visualization paper and pencil test and were asked to participate in a problem-solving task. After the task they were given time to complete a post-activity questionnaire. In total, participants for phase three met with the researcher for 60 to 70 minutes.

3.5.1 Variables

Variables analyzed varied per phase. For the first phase, ‘media channel for informal construction communication’ was the main variable analyzed. The original levels for this variable are indicated in table 3.3. The researcher chose not included an option marked as ‘other’ because the results may not yield significant results. Instead, the most significant levels have been included based on the researcher’s professional experience, literature review, and consultation with other construction professionals in the United States. The questionnaire has been validated (face validity) by two professors from Purdue University with previous work experience, one in landscape architecture and the other in building construction management.

Table 3.3
Variable levels for phase one

Variable	Pre-determined levels
Communication Channel	Face-to-face meeting
	Video-conferencing
	Telephone
	Online Instant Messaging
	Text Message
	Email

In phase 2, interviews provided confirmation of phase 1 results, as well as qualitative information regarding advantages and disadvantages of each of the three main media used. The main focus of phase 2 was to obtain information about recurring problems in construction communication of spatial issues and strategies used to reduce limitations of each of the top three channels obtained through the results of phase 1. This phase also helped develop the case used in phase 3.

In phase three, a full factorial design was used to structure the quasi-experiment. Two independent variables are used in this study: media channel (fixed) and experience (random). Three dependent variables were analyzed: score on the solution of the case given, number of misunderstandings during the period of the exercise, and amount of time used to solve those misunderstandings. The dependent variables are assumed not to interact with each other. A rubric developed by the researcher was used to score phase-three results (see Appendix E); this rubric included work time to execute change, cost of change, constructability of solution, amount of stakeholders involved in solution, solution's effects on other systems, and aesthetics.

Table 3.4
Research design for phase three

Variables		Experience Level	
		Students	Professionals
Communication Channels	Channel 1	XXX	XXX
	Channel 2	XXX	XXX
	Channel 3	XXX	XXX

Table 3.4 summarizes the research design for phase three. Three replications were originally scheduled to be made in order to increase the reliability of findings. If the amount of data collected by the researcher for phase 3 allows for inferential

statistics tests, then the researcher will provide these tests' results. Otherwise, descriptive statistics and qualitative data will be reported for the findings.

3.5.2 Population & Sample

Population for this study is comprised of all professionals related to architectural design and site supervision within general contractors in the American construction industry. This also includes students of related disciplines. Samples from that population varied by phase. Samples for the first two phases came exclusively from the industry, while phase three used two separate samples, one from the industry (professionals) and one from the university (students). Below is a brief description of the sampling for each phase of the study:

- Phase 1: Sample size was determined by a simplified power analysis after the application of a pilot test with the draft questionnaire. In the pilot test, there were five construction management respondents and seven design respondents (total n=12). Based on the findings, an approximation using the proc power statement in SAS was used, yielding a total number of n=5 respondents per channel or n=30 total, per group of respondents. The proc power statement does not take into consideration the repeated measures factor and therefore should be taken with caution. Other power calculations where not feasible due to the low response rate obtained in the pilot. Based on this, the researcher aimed to obtain a number close to 30 respondents in each group (design and site supervision). Stratified random sampling was used to select an equal number of construction companies and design companies from those that received the questionnaire invitations. With this measure, the researcher attempted to provide a balanced sample of design and field personnel. The list of construction companies was obtained from the Associated General Contractors of America (AGC) and the Associated Builders & Contractors (ABC), and the one for architects was obtained from the American Institute of Architects (AIA) directory using the fifty American states as references. Publicly available email addresses were then obtained through internet search engines;

- Phase 2: The sample used for this phase consisted of 8 interviewees identified as construction industry professionals. Four respondents work in design-related jobs and four worked as field personnel for general contractors. The interviewees were selected using a stratified random sampling to assure a balanced number of interviewees from design and field. The list of possible interviewees was obtained though the following methods: by asking participants of phase one, while answering the phase 1 questionnaire, if they would like to be contacted for a follow-up interview; by sending out direct emails to industry professionals from the same population as phase 1; and by inviting professionals during the Fall 2015 Purdue University Construction Management Career Fair;

- Phase 3: The ideal sample totaled at 18 pairs of volunteers, with a minimum acceptable of 6 pairs. Each group had a 'general contractor' and an 'architect' role. Student groups were undergraduate or graduate students from Purdue University. These participants must have had a maximum of one year of full-time work experience in the construction industry. Students who played the role of 'construction manager' were selected from the Building Construction Management (BCM) major. Students who played the role of 'architect' were selected from either the Interior Design or Computer Graphics Technology major. The experienced professionals sample was obtained from the industry. Architects or designers played the role of 'architect' and general contractor's construction related personel played the role of 'construction manager'. Participants had to have at least four years of full-time work experience in the AECO industry. An invitation was sent to design-build companies, facilities owners, and general contractors who had design and field personnel among their employees. Due to time and monetary constraints, professionals were restricted to a 70-mile radius from Purdue University.

The rationale behind the requirements of work experience for students and professionals was to assure the difference between the categories regarding their experience level. It was assumed that students represented novices in the AECO industry and professionals represented a higher level of expertise than students. However, this research was limited in that, due to time and resource limitations, the researcher did not assess the true level of expertise of each participant to establish true measures of expertise in the industry.

Volunteers for phase three were invited by email and flyers. Participants who showed an interest in participating in the study were invited to take the revised version of the Purdue Spatial Visualizations Test (PVST) as part of phase three spatial visualization paper and pencil test. The reliability and construct validity of the revised test are presented in Yoon (2011). The rational for this test was to assess participants' spatial ability, as it could be a source of misunderstandings between participants during the task. More information about this test will be given in the following subsection.

An expedited review from the Institutional Review Board (IRB) was obtained on April 8, 2015, prior to the start of pilot studies for this research, under the approval number #1503015884. The other five amendments were obtained during the course of this study to append revisions to approved documents in light of results obtained in previous phases of research and to adjust recruitment procedures to meet the needs of the researcher and participants. These issues will be discussed in the review of the pilot for phases 1 and 3, as well as in the beginning of Chapter 4 (Results).

3.5.3 Instrumentation

Several instruments were used in this study. In phase 1, a questionnaire was developed by the researcher based on the literature review. Most of the levels for the media channel variables in the questionnaire were extracted from Liu (2009) and Gorse et al. (1999). Some adaptation was necessary due to technology changes since these studies were conducted (fax, hard copy distribution or post/letter were eliminated from the questionnaire) and due to the focus of the present study on informal communication (intranet documentation and meetings were eliminated).

This questionnaire collected the opinions of industry stakeholders regarding communication channels and misunderstandings, as well as demographic data. The goal of this instrument was the assessment of the main media channels used in order to solve a design problem that involved communication between site and office personnel. Two cases were presented to each respondent. Design and field personnel were presented with similar but not identical cases. The cases were adapted to the reality of each stakeholder. They had to choose how helpful each channel was and rank them for each case. Both cases presented a construction issue that involved a spatial problem. Asking respondents the same question can help evaluate the instrument's internal consistency (Sekaran & Bougie, 2010).

The researcher obtained face validity for this instrument by having it assessed by two professors at Purdue University. Also, a pilot test was performed prior to final data collection for phase 1. In the pilot, 400 companies were invited to participate. Results from the pilot study are presented in the following subsection. This preliminary sample was drawn from the same sample as the final questionnaire. The draft for the questionnaire used in the pilot can be found in appendix A.

The second phase of the study consisted of semi-structured interviews with eight subjects. Pilot test interviews were conducted with two professors and one colleague who has previous industry experience in architecture to evaluate the comprehension and wording of the questions. The final version of the questionnaire for phase two can be found in Appendix B.

For phase 3, participants were required to take the PSVT:ROT, which may be considered a measure of spatial ability. This test was used as a complimentary data point of phase 3 data analysis. This test is considered by researchers to be a valid measure for special ability (Yoon, 2011) and has a high score of internal consistency (Cronbachs $\alpha = 0.862$). This test consists of twenty multiple-choice questions. The tester is required to choose the correct answer for the rotation of a three-dimensional shape, based on an example provided for each question. There is a twenty minute limit for the completion of the test.

Also, a case was developed by the researcher for phase 3. This case consisted of a one-page explanation of the problem and constraints which was read aloud and then given to the individual in the site supervision role. Another page containing only constraints was given to the design participant. The final case for phase 3 is presented in Appendix D. Also during the task, both participants were provided with the complete 91-page design set from the public building in Indiana used as the setting for the case. This set of drawings was part of the bidding documents for the building construction and consists of the following design disciplines: Civil, Landscape, Structural, Architecture, Mechanical, Plumbing, and Electrical.

After being given the case, the site supervision personnel communicates the problem to the designer and they should reach an agreement about the best solution. Content validity for this case was determined through consultation with two faculty from the School of Construction Management Technology at Purdue University with more than 10 years of professional experience in the field. A pilot test with two building construction management (BCM) graduate students was also performed in the beginning of January 2016 to assess face validity and correct minor issues. The graduate students used telephone as the channel of communication, a condition that was predefined by the researcher. Issues encountered during this meeting and proposed solutions to each of them were:

- The site supervision participant was verbally told but did not fully understood that only the layout for the first floor should not change, and modification of the second floor layout was not limited. For the final experiment, the researcher printed out constraints and problems and also reworded phrases to emphasize that only the first floor layout was fixed.

- Participants provided two solutions to the researcher, one being the optimal solution and the other an alternate. The researcher stressed the importance of providing only one final solution for the final experiment.

A rubric was also developed for scoring the proposed solutions. This rubric was validated by a BCM faculty with more than ten years of industry experience. The rubric included items such as: constructability, budget & scheduling, complexity, and aesthetics. The complete rubric can be found in Appendix E.

At the end of the experiment, participants were given a questionnaire that included questions about demographic information, and solicited their thoughts on the experiment. The questionnaire applied to participants in phase 3 can be found in appendix C.

3.6 Data Collection

Data collection methods varied by phase. Data for the phase 1 survey was collected online. The researcher used the Qualtrics platform to host and manage survey email invitations. The questionnaire developed and validated (face validity) for this phase was inserted into the system in April of 2015. A pilot test was conducted during April and May of 2015 with twelve respondents. Minor formatting adjustments were made after the pilot data collection and final survey was sent to participants by June 1^{st}, 2015. The electronic survey was closed on July 23^{rd}, 2015. Follow-up emails were sent biweekly to industry professionals.

For phase 1, the response rate was 3.6% for the pilot study (designers and construction and site personnel combined) and 5% for the final data collection of phase 1 (designers and construction and site personnel combined). This rate includes all responses, even the ones containing blank data after question 1. The data collected from the questionnaires was stored in the Qualtrics website until the closing date for the survey. Then, data was exported in .csv format and inserted in SAS and SPSS statistical softwares.

Data collection for phase 2 (interviews) started approximately two months after the completion of phase 1. This allowed time for the researcher to perform data analysis on the results obtained during that phase and select the three main communication media that were to be further assessed during interviews.

Prior to data collection for phase 2, a pilot study was performed with two professors during April 2015. In the pilot, the researcher used face-to-face, telephone and email formats as the mock variables. These channels have been widely studied by Media Richness Theory (Webster & Trevino, 1995). With the exception of email, which is a newer channel, face to face and telephone have also been studied in construction communication research (Emmitt & Gorse, 2003; Liu, 2009). After the end of phase 1 (online survey), a final pilot was conducted with a colleague with industry experience in architectural design to verify possible adjustments and time durations for the interview.

After all the necessary adjustments were made, participants for phase 2 were invited to participate in the interviews. Those who accepted were then given the choice of an online video or voice conference or a regular telephone call for the interview. Only two participants out of the eight total who were interviewed chose to be interviewed by video conferencing; all others used Voice over Internet Protocol (VoIP) with no video. However, due to streaming difficulties during video conferencing, the two participants had to switch to an only VoIP call. In all cases, data collection was made by the researcher by making notes about the participants' responses and also by audio recording the interview for further transcription. This phase occurred between mid-September, 2015 nd the end of October, 2015.

Finally, all data collection for phase 3 occurred at Purdue University's main campus in West Lafayette. Data was collected for this phase during the month of March, 2016. Two pilots were performed in January of 2016, however only one was recorded. Results from these pilots will be presented later in this chapter. Industry and students volunteers who chose to participate in the meeting were compensated with US$20 for their time. As mentioned previously, pilot studies were conducted in mid January, before the final data collection. This procedure allowed the researcher to correct language and procedures to improve clarity for participants, as well as to become familiar with the recording process. During the second pilot study, the researcher's original idea to send out invitations to an online version of the PSVT:ROT in order to reduce the final meeting time was abandoned. More information on the reasons for this choice can be found in the pilot study results at the end of this chapter.

All phase 3 sessions were video recorded for later transcription and analysis. The researcher used individual study rooms in Wang Hall or a computer laboratory in Knoy Hall, depending on the level of media channel selected. During the session, participants took the paper and pencil PSVT:ROT test, participated in the fifteen-minute case (Appendix D), and completed a post-test questionnaire (Appendix C). The final solution for the case presented was indicated on a blank sheet of paper or electronically by participants during their fifteen-minute interaction. The total time participants met with the researcher was 60-70 minutes.

The researcher made notes during the interaction, though video and audio recordings were also used to assure accuracy of transcription and so that both participants could be equally observed. This proved to be a challenge during the real time experience since there was only one researcher available for two participants. The video and audio recorder also helped by providing time stamps for the transcripts, which allowed the researcher to assess the time spent by each group on misunderstandings.

3.7 Data Analysis

Data analysis was performed in-between phases, to fulfill the expectations of a sequential mixed methods study. This means that the data analysis for phase 1 happened prior to data collection for phase 2 and the data analysis for phase 2 happened prior to data collection for phase 3.

For the first phase, the researcher presents descriptive and inferential statistics. Descriptive data provides information about the sample used in the survey and encompasses part three of the survey (see Appendix A). Questions include demographic data from companies and participants.

Inferential analysis used two different measures, the one-way repeated measures analysis of variance (ANOVA) and the Friedman test. The use of two different tests was used to increase reliability of the results. In the survey, the researcher presented two cases with the similar spatial communication to participants. In both cases, respondents' choice of channels was assessed by a five-point Likert-type scale and a ranking scale. Qualitative open-ended questions were also presented to participants who wished to provide more information regarding their choice.

Both repeated measures ANOVA and Friedman tests were used to detect significant differences between levels at $\alpha = 5\%$ level. A Tukey adjustment was performed on the post-hoc ANOVA test. The Friedman test is already considered to be conservative, so no adjusment was made to the $\alpha = 5\%$ level in the post-hoc Wilcoxon test. Since, in this study, the researcher was strictly interested in the channels presented (face to face, telephone, email, videoconferencing, online instant messaging, and text message), the communication channel was considered fixed. Previous researchers in the field of construction communication have used similar statistical tests for data analysis (Emmitt & Gorse, 2003; Liu, 2009).

The hypotheses used for the repeated measures ANOVA tests in phase 1 were:

H_0 = *there is no significant difference between communication channels*

H_a = *there is a significant difference between communication channels*

The researcher has checked for the following assumptions: normal distribution and population variance between levels. These assumptions are required in order to be able to perform the repeated ANOVA testing. The repeated measures ANOVA does not require independence of answers as it is used in cases in which the levels (in this case, different channels) are used in the same sample.

The Friedman test does not require a normal distribution because it follows a nonparametric distribution. The hypotheses used for the Friedman test were:

H_0 = *there is no significant difference between communication channels*

H_a = *there is a significant difference between communication channels*

All statistical analysis was performed in SPSS and SAS, depending on the test performed. The outcome of this phase served to select the three most preferred communication channels to be used in sub-sequential phases.

Data collected from the second phase (interviews) was transcribed in order to be analyzed. Transcription was performed by the researcher during the course of two months, as other interviews were being conducted. Data for this phase was reported in a summary fashion for part one (normal work process), two (problem solving), and four (demographics) to inform readers about the samples being interviewed.

For part three (design problem solving), the researcher presented the results as a summary and also analyzed answers to identify:

1. common design problems;
2. channels mostly used;
3. channels advantages and disadvantages;
4. problem solving strategies.

Item one in the list above provided the researcher with possible ideas to develop the phase 3 case. Item two was used to compare with phase 1 findings. Finally, items three and four provided an indication for the researcher of the possible keywords to use for phase three qualitative analysis.

The main researcher and an assistant analyzed the anonymized data using the pre-determined codes mentioned in the aforementioned list. This was done to select data from the interviews during the first analysis. The assistant coder for phase 2 was a current graduate student from the School of Construction Management technology, with 11 years of experience in an academic setting. Her background in architectural engineering and construction offered an opportunity to verify the analysis by an individual with a different, but related background. A second pass on the coded data was performed by the main researcher in order to organize the data into main emerging themes for each code.

Also, in order to help improve analysis of interview data, word clouds were also done using the data to verify how communication channels were mentioned by participants. Heimerl, Lohmann, Lange, and Ertl (2014) indicate that word clouds aid in text analysis by indicating words of highest frequency. De Hollander and Marx (2011) differentiate "word cloud" from "tag cloud." Essentially, the difference between them is that a tag cloud is built from tags that users give to a document while word cloud uses all the words in a document or part of a document (De Hollander & Marx, 2011).

Frequency per code is reported in chapter 4 (Results). The researcher used NVivo software for developing the word cloud and coding and analysing the interview transcripts.

Data collected in phase 3 was analyzed quantitatively and qualitatively. Quantitative data was analyzed and reported using descriptive statistics. This data included: score of solution, number of misunderstandings, and time to solve misunderstandings. The descriptive data helped the researcher to assess differences and similarities between combinations of variables.

Qualitative analysis for phase 3 included analysis of observations made from video recording during the sessions. Audio from sessions was also transcribed. Just as in phase 2, software NVivo was used for coding the transcripts. In this analysis, the researcher focused on the strategies used by the group to solve misunderstandings and on how these differ from one media to the other and between students and professionals.

The coding system developed by Stempfle and Badke-Schaub (2002) was also used to code the overall task. This allowed the researcher to compare results found in this task to the ones reported by Stempfle and Badke-Schaub (2002). However, some differences must be indicated: Stempfle and Badke-Schaub (2002) analyzed teams containing four to six student participants who had worked on a complex design problem for a one-day period. Analysis of the students' discourse was performed based on their communication acts. More than one communication act could be included in longer discourses. Because of the time constraint of fifteen minutes imposed on participants in this dissertations' phase 3 task, the author coded words instead of communication acts, and reported the number of communication turns (defined as when the communication changes from one participant to the other). This author finds that by coding the number of words, one can have a better understanding of the amount of information transmitted, given the shorter time available. The organization of coded words over the progression of the task will also be presented, similarly to Stempfle and Badke-Schaub (2002). This allows for readers to grasp the dynamics of how participants structured their approach to the problem during their time together.

Also, any indication of negative or positive behavior regarding problem solving strategies was noted to inform the researcher of possible confounding factors. D'Zurilla, Maydeu-Olivares, and Gallardo-Pujol (2011) indicate some perceivable differences in problem orientation. In the case of positive behavior, the solver sees the problem as a solvable 'challenge' that may be overcome; in negative behavior, the solver sees the problem as an unsolvable ‘threat,’ where the attempt to solving can lead to frustration.

The researcher analyzed the questionnaires for phase 3, reporting the results in a summary fashion. Demographic descriptive data reporting was employed to describe the sample. Open-ended questions 3 (‘If given another chance, what would you do differently?’) and 9 (‘If some misunderstanding occurred in the task, explain how you and your peer overcame these difficulties’) were analyzed to look for common themes. These two questions aided the researcher in understanding possible strategies used or articulated by the solvers to improve their problem solving skills in this task.

The analysis provided the researcher with enough information regarding how professionals and students use media channels and how they communicate as a team to solve a design problem related to space. These results were then compared with existing literature, and they guided the researcher in proposing guidelines for effective communication in design problem-solving tasks.

Finally, results obtained and analyzed for all three phases were synthesized to create guidelines for improved communication between design and site supervision personnel. These guidelines represent the conclusion of this research and focus on suggesting strategies for more effective communication. Two Purdue faculty with industry experience, one from the design side and one from construction, were invited to review and comment the developed guidelines in order to obtain partial validity.

3.8 Pilot Study Results

As mentioned previously, pilot studies for phase 1 and phase 3 were performed by the researcher prior to the final data collection. The findings from these pilots are described in the following subsections.

3.8.1 Phase 1: Pilot Study results

Four hundred companies were invited to take the online survey prepared by the researcher for phase 1. Two hundred of these were from the AIA directory list, one hundred from ABC, and one hundred from AGC. Eighteen emails bounced back, resulting in a total of 382 successfully sent emails. Two weekly reminders were sent for each company after the original email was sent. The final response rate for the survey was fourteen responses. Of those fourteen, two were blank, leaving the researcher with twelve surveys to be used for the pilot data analysis. This indicates a final response rate of 3.1% (excluding blank surveys and unsuccessfully sent emails). Given the low response rate in the first two weeks, calls were made to a randomly selected number of companies indicated in the original sample for the pilot during the third week. No significant increase of respondents was noticed after this procedure and during the third week of data collection for the pilot. The response rate obtained is still significantly lower than the 15% reported by Liu (2009).

Some possible causes for the low response rate might be electronic email filtering, which could cause the sent email to arrive in spam folders. Also, during the phone contact, many respondents alleged lack of time due to the great amount of work or bidding processes underway.

Even though response was low, the data collected allowed for preliminary analysis in order to evaluate whether the on-line survey could be used for the final data collection. A good balance between architecture (n=7) and general contractors (n=5) was obtained. Not all of the total twelve participants who answered the cases' questions completed the demographic session for the survey. Table 3.5 shows the distribution of work location of respondents for the pilot study.

As for size of companies, five respondents estimated their company to have between 50 and 249 employees, three of them between 10 and 49 employees, and three of them less than nine employees. This number is consistent with the United States Census Bureau data from 2012 (US Bureau of Labor Statistics, 2014), which indicates that companies with fewer than 500 employees constitute 640,055 out of

Table 3.5
Distribution of current work location - survey pilot (n=11)

Region	Comprising States	#Respondents
Pacific	AK, CA, HI, OR, WA	1
Mountain	AZ, CO, ID, MT, NM, NV, UT, WY	1
West North Central	KS, IA, MN, MO, ND, NE, SD	1
East North Central	IL, IN, MI, OH, WI	3
West South Central	AR, LA, OK, TX	0
East South Central	AL, KY, MS, TN	1
South Atlantic	DC, DE, FL, GA, MD, NC, SC, WV	3
Middle Atlantic	NJ, NA, PA	0
New England	CT, MA, ME, NH, RI, VT	1

the total number of 640,951 construction companies in the United States. This means that companies with fewer than 500 employees account for 83.3% of the total number of construction companies in the US, while bigger companies are responsible for only 16.7%.

The type of construction or design performed by the companies surveyed during the pilot study was varied, as shown in table 3.6. Note that participants could select more than one option for type of work performed.

Professional experience of respondents ranged from five to thirty five years of experience, with a mean of 23 years. Respondents indicated that they communicated with either site or design personnel from once to more than twice a week (55% of respondents) to more than that (45% of respondents). The median age of respondents was in the 40 to 49 group, and all eleven respondents who chose to disclose their gender were male. The sample was small, but this is consistent with current statistics indicating that female participation in construction management is 7.3% and in architecture and engineering management 10.3%, though it is

Table 3.6
Distribution of type of construction or design - survey pilot (n=11)

Type of Construction	#Respondents
open or recreational spaces	3
retail construction	5
residential	2
general commercial	6
heavy civil	0
healthcare and laboratories	7
institutional	6
warehouses and manufacturing buildings	6
hospitality	4

significantly smaller than the average for architects (25%) and for civil engineers (12.1%), as provided by US Bureau of Labor Statistics (2014).

Ten respondents had at least a college education; five of them had architectural degrees, three had construction management degrees, one had an architectural engineering degree, and one had a management degree. One respondent indicated having only a high school degree.

Statistical tests were performed to verify the existence of any problems in the questionnaire. First, correlations between the first and second cases were taken, and they have presented high correlation ($r > 0.8$) for three channels (face to face, videoconferencing, and online instant messaging) in both groups, one of them (email) presenting medium correlations coefficients ($0.6 < r < 0.8$) in both groups. Text message had a high correlation for site supervision personnel ($r > 0.8$) and medium correlation for designers ($0.6 < r < 0.8$). Telephone presented a negative medium correlation in both groups with $r = -0.41$ for site supervision personnel, and $r = -0.57$ for designers. The researcher reevaluated the cases and the results obtained in the quantitative and qualitative analysis and chose not to change the cases, as correlations were good for most channels. The low and negative correlation could also be caused by personal variability and small data set.

Table 3.7
Descriptive statistics for channel variables - design personnel

Variable	Respondents	Mean[a]	Standard Deviation
Face to face meeting	5	4.60	0.894
Telephone	5	4.00	0.707
Email	5	4.00	1.225
Videoconferencing	5	1.80	1.304
Online Instant Messaging	5	1.40	0.548
Text Message	5	1.40	0.548

[a] for a 5-point Likert-type scale from 1=unutilized... to 5=very helpful

Table 3.7 summarizes the mean and standard deviation for channels presented in the first cases for design personnel and table 3.8 summarizes the one for site supervision personnel. It is interesting to see the high variability of videoconferencing, indicating that this channel might be undergoing a change in use pattern in the AECO industry.

In order to measure the internal consistency of the questionnaire, the researcher calculated the Chronbachs alpha for the Likert scale items in both cases, for designers and site supervision personel combined. The number obtained ($\alpha = 0.865$) is above the threshold (0.70) for adequate internal consistency (Santos, 1999).

Two inferential tests were also performed on the data: the Friedman test and a repeated measures Analysis of Variance (ANOVA). For both cases, the researcher utilized the first case responses because several respondents did not complete the

Table 3.8
Descriptive statistics for channel variables - site supervision personnel

Variable	Respondents	Mean[a]	Standard Deviation
Face to face meeting	7	5.00	0.000
Telephone	7	4.00	0.577
Email	7	3.71	0.488
Videoconferencing	7	2.57	1.618
Text Message	7	2.43	0.976
Online Instant Messaging	7	2.29	0.951

[a] for a 5-point Likert-type scale from 1=unutilized... to 5=very helpful

second case. This choice also takes into account the correlation measured between the first and second case.

The Friedman test, which measures the differences between rank responses, presented a $\chi^2 = 12.26$ ($\rho = 0.003$) for design personnel and a $\chi^2 = 26.77$ ($\rho < 0.000$) for site supervision personnel. Therefore, for both groups there is a significant difference between channels. Based on the mean ranks displayed in the test, the researcher conducted further post-hoc tests for the most well-evaluated four channels (face-to-face meeting, telephone, email and video conferencing), as the researcher was interested in selecting the three perceived as most useful.

Utilizing $\alpha = 0.5\%$ for the four tests, a Wilcoxon Signed Rank test was performed. Significant difference was found ($\alpha < 0.5\%$, $\rho = 0.038$) only between face to face and video conferencing. No other pairwise comparison was significant at the $\alpha = 0.5\%$ level. This could be due to the small sample size in consideration. A Bonferroni adjustment was not done due to the conservative and non-parametric nature of the Wilcoxon test.

Following the Friedman test, a repeated measures ANOVA was performed in which the researcher could block the variance by subject. This was performed on the Likert-type scale questions for case one. Assumption for normality was met. The repeated measures ANOVA did not require independence.

The repeated measures ANOVA results indicate that there is no significant difference between designers and site supervision personel regarding perceived helpfulness of each channel (F=3.42 and $\rho = 0.0712$). On the other hand, the ANOVA test has shown that there exists at least a pair of channels that are significantly different from each other (F=12.06 and $\rho = 0.002$ for design personnel; F=11.57 and $\rho = 0.002$ for site supervision personnel). Pairwise, the ANOVA post-hoc tests were not performed due to the small data set.

Qualitative analysis of data indicated that most respondents preferred face-to-face because of the directness of communication. Participants also mentioned choosing face-to-face because describing spaces verbally can be difficult and face-to-face allows for other visual aids. At least one respondet indicated a low usage of email and videoconferencing due to connectivity problems in the work area. One respondet indicated the preference for email, in order to maintain a record of communication.

Based on these findings, the researcher decided not to alter the pilot questionnaire and to proceed with the final phase one data collection. The target sample size for the final data collection determined based on the pilot data was 24 for design respondents and 12 for construction related respondents, totaling 36 respondents for the final phase 1 data collection.

3.8.2 Phase 3: Professionals' Pilot Study Results

The researcher also performed a second pilot study for the quasi-experiment with industry professionals. In this meeting, participants were asked to use face to face communication during the problem solving task.

Prior to this meeting, the researcher sent participants an invitation to take the PSVT:R online. However, the construction professionals who participated indicated difficulties accessing the online test as well as frustration in finishing the test due to how long time figures and questions took to appear on the screen. The researcher gave this consideration and decided to only use the paper and pencil version during phase 3 meetings. Results obtained showed the CM participant with a score of 8/30 and the design participant with a score of 26/30.

Both participants were females. The CM participant obtained a construction management undergraduate degree and the designer an architecture undergraduate degree. Both professionals had four or more years of professional experience: the designer had four years while the construction professional had twenty. Both indicated in the post-test questionnaire that they preferred face-to-face for professional communication. However, the designer preferred videoconferencing as second and email as third while the construction participant preferred telephone as a second means of professional communication and email as a third.

Figure 3.3. Adjacent rooms used for phase 3 pilot studies

The following paragraphs report the findings from that pilot session. After both participants arrived in the previously arranged meeting location, they introduced themselves and were then placed in separate (adjacent) rooms to review the plans used in the problem solving task. Figure 3.3 shows the layout of one of the rooms used for this pilot experiment as well as subsequent data collections for face-to-face and telephone communication.

Each participant was asked to take three minutes to review the plans individually. Both rooms were monitored by a video camera. When the three minutes was over, the researcher asked the construction participant to listen to the case while the designer could continue to look over the plans. The following quote presents the problem as it was described to the 'project manager on site' (CM) role:

> You are the construction project manager for this project. You are on site and the data equipment company came to inspect your construction. They asked to look at the drawings and did a tour of the site. You have just finished erecting your structure. They said to you that they cannot have any pipes passing over the data room (HVAC ducts are okay). Plumbing installation will start in 2 weeks and all the material has been ordered already. The plumbing engineer said he is willing to change drawings, but he wants you to talk to the architect first and propose a solution for him to work with.
>
> Two things you remember are that (1) gear lockers in the adjacent wall are floor to ceiling and the fire station does not allow for soffits inside lockers. (2) both floor layouts have been approved by the client for months, and there is a strict requirement only for the first floor layout not to change.
>
> Please talk to the architect and find a solution to this problem.
>
> The architect does not know about the issue and you must explain it to him or her.

After explaining the case, the researcher asked if there were any questions from the construction (CM) participant. The CM asked if they could argue with the equipment manufacturer about this issue and try to solve the situation with them prior to changing the design. This was not anticipated by the researcher, however, given the situation, the researcher mentioned that the construction personnel had already tried this approach unsuccessfully and that the only viable option now was to discuss other solutions with the architect.

The researcher also provided a printed copy of the case for the construction personnel in the task as well as a printed copy of the constraints to the architect. This copy read:

> [Constraints for design personnel] Two things you remember are that (1) gear lockers in the adjacent wall are floor to ceiling, and the fire station does not allow for soffits inside lockers. (2) both floor layouts have been approved by the client for months, and there is a strict requirement only for the first floor layout not to change.

After the designer received her copy of the constraints, the CM was invited to join her, in the room where the designer was reviewing the plans. The researcher mentioned they would have 15 minutes starting at that moment to come up with one best solution for this issue. The best solution should be written down on a blank white letter paper provided to them. After this explanation, the researcher closed the study room door and let the participants discuss the case.

Interaction between participants seemed to flow well. First, the CM participant explained the issue to the designer, who listened patiently. They went over the plans to identify the equipment room. Then, they quickly looked through the mechanical HVAC drawings and finally over the plumbing drawings. For several moments, the designer and CM pointed at the plans in order to indicate the spaces or rooms they were talking about, along with words like 'this room', and 'here.' An example of this behavior is the following extract from the CM: "So look, here is ductwork. . . here is first floor plumbing. So let's look at that." An example also comes from the designer: "We have a storage room in here. . . and we have. . . what's this in here? It looks like there is plumbing in here. . . "

When looking over the plumbing drawings, both participants visualized the amount of plumbing lines over the equipment room and started brainstorming possible ideas of how they could solve the issue. A limitation of this pilot is that the camera used for video and audio recording malfunctioned and the recording stopped at 9 minutes and 31 seconds. However, some of the ideas extracted from that recording were:

- Swap the toilet room with other room on the second floor;
- Reroute lines through the corridor on the first floor;
- Grow the toilet on the second floor so the plumbing can be rerouted out from the equipment room and into the adjacent room;

Both participants thought the problem was hard and that there were many unknowns, such as not being able to know the whole story of the project and the reasoning behind the layout for the floor. Another issue participants identified was not being able to talk to the equipment company to work out a solution with them and having the equipment layout to negotiate. The second issue the CM mentioned during the task was that, as is common in construction, one is not always able to discuss issues with vendors.

The final solution presented was written on a blank piece of paper, as requested: "Relocate restroom #213 to #202. Accept minor add-in plumbing reroute and additional work. Prioritize security of data room. Relocate plumbing above." The solution was presented hand-written and in bullet points during the last minute of the task. Based on the rubric presented in appendix D, in which the main parameters include constructability (CS), scheduling & budget (SB), complexity (CX), and aesthetics and usability (AU), this solution was scored as (4 [CS] + 1 [SB] + 2 [CX] + 1 [AU] =) 8/10. This solution lost two points because it would have caused some extra costs (minus 1 point) and would probably have affected the electrical and HVAC disciplines due to the room swap (minus 1 point).

In the post-task questionnaire, both participants indicated that they had no misunderstandings during the task and that team dynamics was pleasant. However, they differed on solutions satisfaction. The designer was satisfied with the solution while the construction professional was not. Both recognized the limitations of time and of information available during the task and thought it was harder then it seemed first glance.

Table 3.9
Professionals, face-to-face: content exchanged - pilot

Code	Words Coded
Goal Clarification	514
Solution Generation	133
Analysis	717
Evaluation	80
Decision	0
Control	0

In order to analyze how content flowed during the task, as defined by Stempfle and Badke-Schaub (2002), the researcher summarized the findings in table 3.9 and figure 3.4. Table 3.9 presents the breakdown for each code present during the available video time, which was then transcribed. Analysis is the predominant code, followed shortly by goal clarification. It is expected that, as time progressed during the task, more evaluation and decision codes would be present. However, due to video malfunction, the researcher was only able to partially capture the conversation content. This group had 96 conversation turns captured until the video malfunctioned (moment during which the conversation shifts from one team member to another).

Analyzing the graph presented in figure 3.4, one can see that the group took the first part of the task to clarify goals. The five minute mark is shown as a red dotted line. Goal clarification also included briefing the designer about the problem. Then, a series of solution generation and analysis took place. For some brief

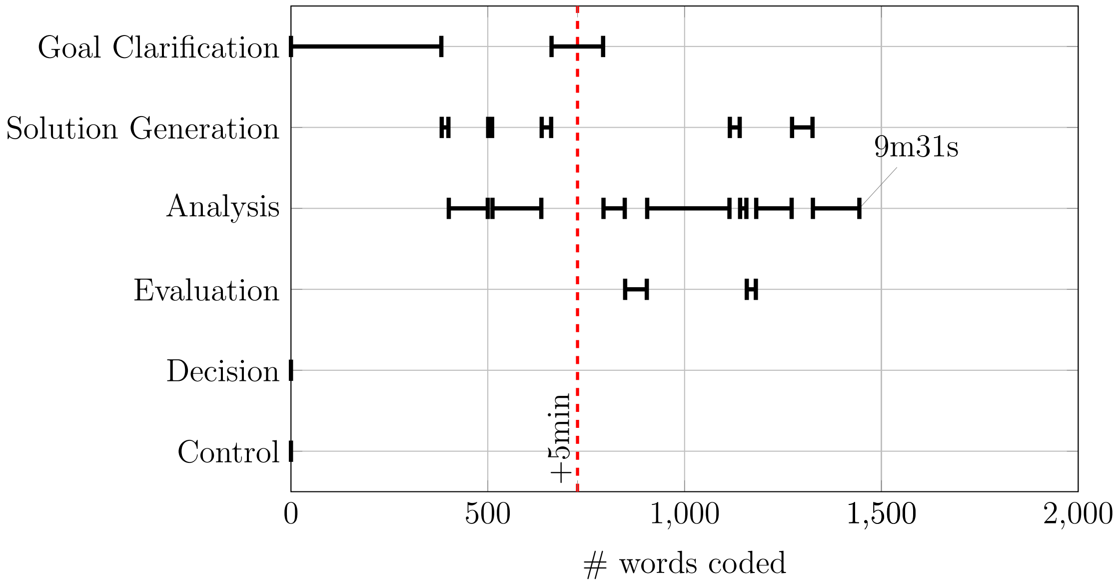


Figure 3.4. Professionals, face-to-face: content exchanged over task progress - pilot.

periods, participants went back to goal clarification mode to make sure they had all the information needed and to ascertain there was any other information that could help in the task. Again, the researcher was limited to the 9m31s of video recording available for this group, which corresponded to 1,444 transcribed words.

The task allowed participants to draw on each other's experience, and this type of interaction was captured during the task, such as when the construction manager asked the architect for her opinion:

> CM: I would guess - and you would know better as an architect, right? - that the relationship of these rooms to each other is important, and we can't just pull one out. I think we need to reroute, but I don't know ...
>
> A: Yeah, I'm just wondering, say, if we have the shower, and we have the toilet, and we have the sink, like, how do we prevent... you know, there is always going to be a section of pipe, where we are rerouting it, that is over the data room. Like how much can we reroute it...
>
> CM: Oh...

Through the analysis of the task and the solution generated by the group, the researcher was satisfied with the case presented to participants. Measures for assuring the recording would be obtained were established for the next interactions. One example of a mitigating measure taken by the researcher during the following meetings was placing an audio recorder close to each team member as a backup device in the case video recorder did not work.

3.9 Summary

This chapter presented the rationale, framework, and methods used to collect and analyze data for this dissertation. This study proposed a three-phased sequential mixed methods approach. During phase 1, the researcher collected data through a survey from the industry. The goal for this phase was to provide the researcher with information in order to select the communication channels that could be further assessed in the following phases.

For phase 2, interviews were conducted, transcribed, coded and analyzed. Input from this phase helped the researcher to develop the case for phase 3, as well as obtain more information about how communication channels influence construction communication.

Finally, phase 3 of this study used a quasi-experiment approach. During the task, the researcher observed the behavior of pairs of students and pairs of professionals using certain communication channels to solve a construction problem. Making the participants use only one channel of communication exacerbates the constraints they might find in everyday design problem solving. The strategies used by participants to reduce misunderstandings and improve effectiveness of communication were observed and analyzed.

Information from the three phases were reported and compared to findings from previous studies. This synthesis with previous literature helps the researcher understand the differences between channels and experience levels in order to provide industry stakeholders with useful guidelines for reducing communication breakdowns in design problem solving during the construction stage. Results from all three phases are presented in the following chapter.

CHAPTER 4. RESULTS

In this chapter, the researcher presents the results for the three phases of this mixed methods study. Results are presented by phase, followed by a discussion for each phase.

4.1 Phase 1 - Online Survey

As mentioned in the previous chapter, the researcher will first present a descriptive analysis of the sample demographics and then an inferential analysis based on the results obtained. At the end of this section, the researcher will discuss the reporting of qualitative data that participants shared in the survey.

Invitation emails were sent to 641 architectural companies and 826 construction companies throughout the country in the beginning of June 2015. Three reminders were also made between the months of June and July. The survey was closed on July 23rd, 2015. An internal consistency analysis was performed in Likert scales items for both cases and both roles. The researcher found that $\alpha = 0.598$. This is significantly lower than the coefficient found in the pilot test ($\alpha = 0.865$), indicating that the scale may not be unidimensional (Tavakol & Dennick, 2011). This is a possibility, since the researcher asked professionals about their opinions regarding several different channels.

A solution for this was to analyze separate alphas for each channel. This analysis indicated a high ($\alpha > 0.70$) internal consistency for face-to-face ($\alpha = 0.727$), videoconferencing ($\alpha = 0.743$), telephone ($\alpha = 0.746$), online instant messaging ($\alpha = 0.794$), and text message ($\alpha = 0.832$). Email was the only scale that presented an internal consistency lower than the 0.70 threshold ($\alpha = 0.597$). An estimate lower than 0.70 for internal consistency in email is not ideal, but this value is influenced by the low number of questions in the scale (n=2); therefore, it must be taken with caution as it may indicate an underestimate (Tavakol & Dennick, 2011). A limitation of this phase is not having included more questions to solve the issue. On the other hand, one of the main challenges in developing the questionnaire was keeping questions to a minimum in hopes of having respondents complete all items.

4.1.1 Sample Demographics

The total number of respondents for the survey was 73. Three categories were not taken into account (designers who indicated they do not interact with site supervision, site supervision personnel who indicated they do not interact with designers, and professionals who indicated other roles, meaning neither designer nor site supervision personnel) and were dismissed from taking the following survey questions. Figure 4.1 presents the distribution of survey participants per professional role.

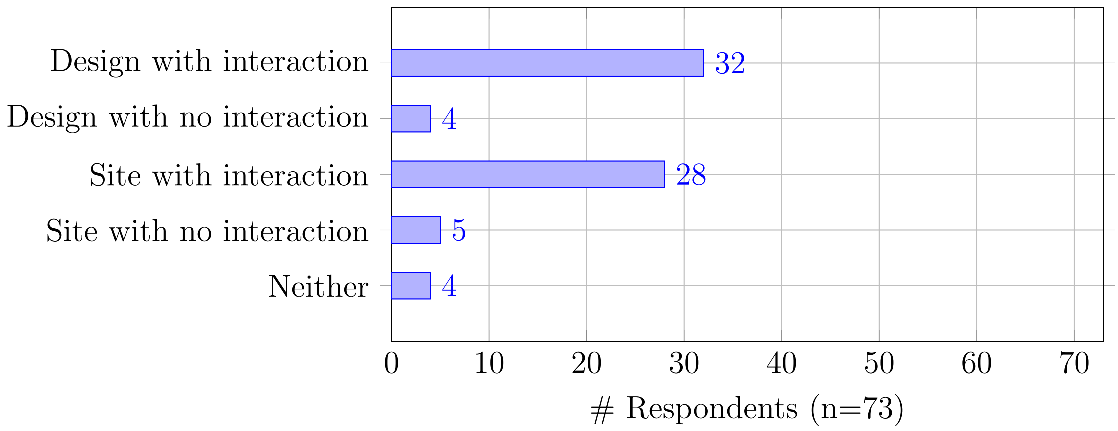


Figure 4.1. Professional role of survey participants

From the remaining participants, three designers and five site supervision personnel were excluded because they did not complete any of the subsequent survey questions. One designer was eliminated due to inconsistent data. Therefore, the total number of participants for phase one was n=51, of which 28 were designers and 23 site supervision personnel.

Regional distribution[1] seems to be concentrated in the East North Central Region, making up a third of the responses. Most regions were represented in the survey, with the exception of East South Central region. Figure 4.2 presents the distribution of survey participants per US region. Three participants did not respond to the question about current work location.

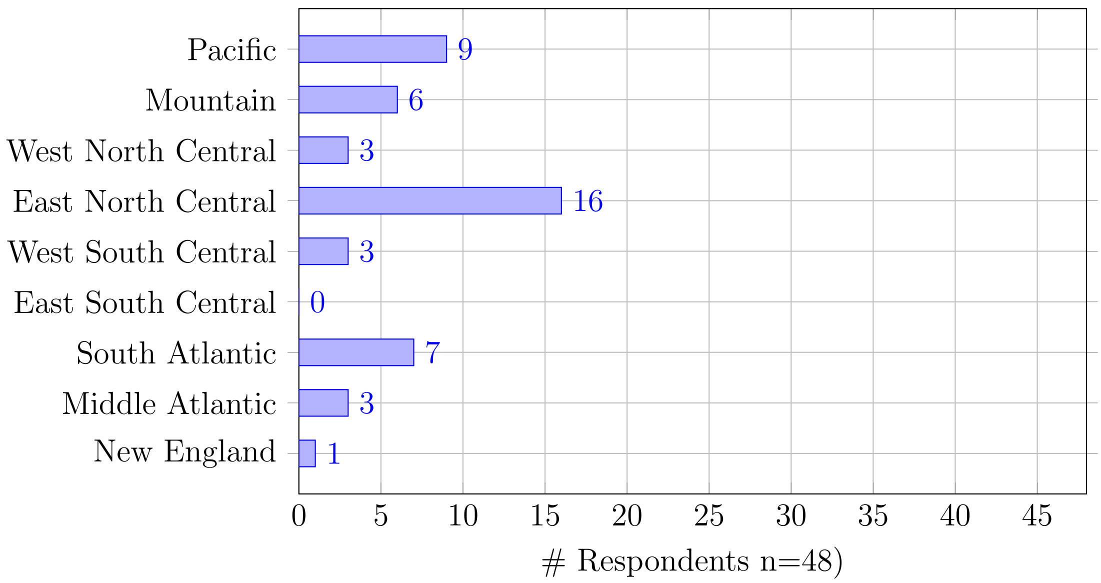


Figure 4.2. Current work location of survey participants

The size of companies also was similar to what was found during the pilot study, with 54% of participants coming from companies with fewer than 50

[1]Regional distribution of states considered:
Pacific: AK, CA, HI, OR, WA
Mountain: AZ, CO, ID, MT, NM, NV, UT, WY
West North Central: KS, IA, MN, MO, ND, NE, SD
East North Central: IL, IN, MI, OH, WI
West South Central: AR, LA, OK, TX
East South Central: AL, KY, MS, TN
South Atlantic: DC, DE, FL, GA, MD, NC, SC, WV
Middle Atlantic: NJ, NA, PA
New England: CT, MA, ME, NH, RI, VT

employees. Six respondents were from companies with between 50 and 249 employees, 10 from companies with between 250 and 999, only one respondent from companies with between 1,000 and 4,999, and finally, five respondents from companies with more than 5,000 employees.

Most of the participants built or designed general commercial buildings. Several companies worked in more than one type of construction. Figure 4.3 presents the type of work participants' companies provided.

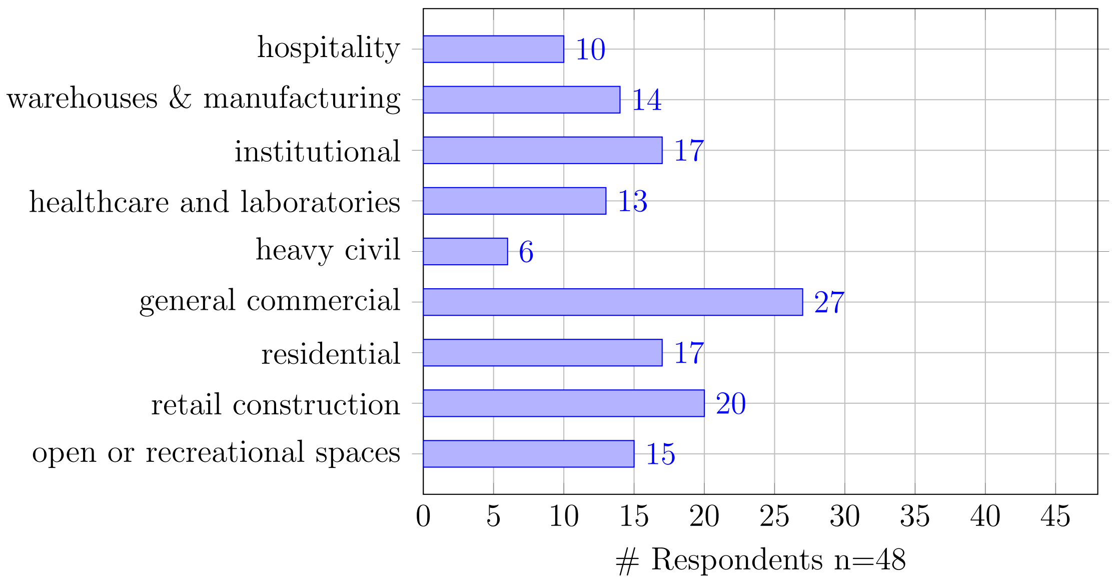


Figure 4.3. Type of construction performed by participants' companies

Average full-time experience in construction or design ranged from zero years to 48, with a mean of 24.51 years and a median of 28 years.

The researcher also asked participants to rank the use of the six communication channels - face-to-face, telephone, email, text message, video conferencing and online instant messaging - for general professional and personal reasons. Number 1 indicated the most helpful channel, while number 6 the least helpful. Findings are presented in 4.1 and 4.2 below for site supervision and design personnel combined. The results indicate a great difference in choice of communications between the workplace and personal use.

Table 4.1
Ranking of channels for general professional reasons

Channel	Respondents	Mean[a]	Standard Deviation
Telephone	43	1.93	0.88
Face-to-face	43	2.05	1.05
Email	43	2.30	0.89
Videoconferencing	43	4.44	0.91
Text Message	43	4.47	0.83
Online Instant Messaging	43	5.81	0.50

[a] the ranking system considered 1=most helpful... to 6=least helpful

Table 4.2
Ranking of channels for general personal reasons

Channel	Respondents	Mean[a]	Standard Deviation
Telephone	48	2.10	1.19
Face-to-face	48	2.38	1.52
Text Message	48	2.79	1.27
Email	48	3.67	1.02
Videoconferencing	48	4.85	1.30
Online Instant Messaging	48	5.21	1.05

[a] the ranking system considered 1=most helpful... to 6=least helpful

Frequency of communication between stakeholders (designers and site supervision) also varied, but 48% of participants indicated that they talk with site supervision or design personnel at least once per day.

Median age range of participants in the online survey was 50-59. Four respondents were between the ages of 18 and 24, one was between 25 and 29, nine between 30 and 39, eight between 40 and 49, 15 between 50 and 59, nine between 60 and 69, and two aged 70 or above. Seventy-seven percent of respondents were males and only 23% were females.

Four respondents indicated that they only have a high-school degree, while thirty had college degrees, one had an MBA degree, and fourteen participants had Master's degrees. Of the participants with higher education degrees, twenty-one had an architectural degree, one an interior design degree, four civil engineering degrees, thirteen construction management degrees, two architectural engineering degrees, and two indicated other degrees (business administration and criminal justice).

4.1.2 Inferential Statistical Tests

First, correlations for cases one and two for each channel were analyzed for each role to verify if the researcher achieved consistency of answers. Interesting findings were discovered. Higher correlations were found in site supervision personnel answers. Face-to-face (r=0.863), telephone (r=0.864), and online instant messaging (r=0.830) presented high correlations (r >0.80) for site supervision personnel. Medium to high correlations (0.80 >r >0.60) were found for videoconferencing (r=0.638) and text messaging (r=0.647) with site supervision personnel and text messaging (r=0.772) with designers. Medium and medium weak correlations (0.60 >r >0.40) were found for site supervision email (r=0.468), and designers using online instant messaging (r=0.516) and videoconferencing (r=0.571). Weak to very weak correlations (0.40 >r >0.20) were found for designers using face-to-face (r=0.246), telephone (r=0.315), and email (r=0.374). In light of these findings, the researcher decided to analyze both case one and case two in the ANOVAs.

Inferential statistical tests were performed on the data per group in order to understand if there were significant differences between channels when dealing with urgent design problems. Each professional group was presented with two cases.

Both cases described a brief issue that required site supervision and design personnel communication. Each case varied slightly to accommodate professional characteristics of each group. Cases presented were:

- *Site Supervision, Case 1:* You are in the field and your workers call you because they are having problems to fit all pipes within the space specified in the construction drawings due to unforeseen conditions. You need to understand why this happened and find a quick solution to keep up with the work schedule. After going over all construction documents available, you decide to communicate directly with design personnel for causes and possible solutions.

- *Site Supervision, Case 2:* You are in the field and your workers call you because they are having problems locating some power outlets because of the window sill heights. You have some options to fix this, such as rotating, dislocating, or simply changing the heights. You need to discuss this with the design department in order to find a solution that does not interfere with design standards and specifications previously approved by the client. You are already late on schedule, and you need to make a decision fast.

- *Design, Case 1:* Your client went to the field and complained that the ceilings were not placed according to previously approved architectural drawings and specifications. He did not mention which, but just that they were close to the main building entrance. You need to confirm with site personnel which ceilings were built, and make sure the heights and design in accordance with the specifications.

- *Design, Case 2:* After a design meeting, there is a decision to change the sizes of some structural beams (height and width) due to structural redefinition of the project. Construction is on schedule and site crew might have already erected some of these beams on site. You need this information fast in order to define a plan of action. You need to contact field personnel to find this out urgently.

First, two separate repeated measures ANOVAs were performed to understand if there were significant differences between genders. Significance was tested at the $\alpha = 0.05$ level. Hypotheses for the gender test are presented below and are repeated for each role (designer, site supervision personnel) and case (case 1, case 2).

For gender differences:

H_0 = *there is no significant difference between males and females related to channel helpfulness for design problems*

H_a = *there is a significant difference between males and females personnel related to channel helpfulness for design problems*

All four ANOVA tests performed indicate that we cannot reject the null hypotheses for gender differences (designers case 1 F=0.363 and $\rho = 0.554$; designers case 2 F=0.917 and $\rho = 0.348$; site supervision personnel case 1 F=0.399 and $\rho = 0.535$; designers case 2 F=1.586 and $\rho = 0.223$). Therefore, there seems to be no difference between genders for design and site supervision personnel in regards to choosing the most helpful communication channel for design problems.

Following the test for gender differences, the researcher analyzed descriptive statistics for channels for each role, collected for Likert-type questions. The Likert scale presented the following alternatives for channel use: unutilized (1), of little help (2), moderately helpful (3), helpful (4), and very helpful (5). Results are presented in tables 4.3 through 4.6.

Descriptive statistics show a higher standard deviation in channel helpfulness than the pilot study. It is also interesting to note that text messaging seems to have a higher mean than videoconferencing. This is opposite from the findings discovered during the pilot.

Table 4.3

Descriptive statistics for channel variables - design personnel case 1

Variable	Respondents	Mean[a]	Standard Deviation
Face-to-face meeting	27	4.59	0.971
Telephone	28	4.21	0.738
Email	28	3.93	1.152
Text Message	27	2.70	1.265
Videoconferencing	26	2.65	1.441
Online Instant Messaging	28	2.04	1.138

[a] for a 5-point Likert-type scale from 1=unutilized... to 5=very helpful

Table 4.4

Descriptive statistics for channel variables - design personnel case 2

Variable	Respondents	Mean[a]	Standard Deviation
Face-to-face meeting	26	4.58	0.857
Telephone	26	4.73	0.533
Email	26	3.96	1.148
Text Message	26	2.88	1.423
Videoconferencing	26	2.35	1.325
Online Instant Messaging	26	1.85	1.120

[a] for a 5-point Likert-type scale from 1=unutilized... to 5=very helpful

Table 4.5

Descriptive statistics for channel variables - site supervision personnel case 1

Variable	Respondents	Mean[a]	Standard Deviation
Face-to-face meeting	23	4.28	1.123
Telephone	23	4.13	0.757
Email	23	3.61	0.891
Text Message	23	2.70	1.185
Videoconferencing	23	2.57	1.343
Online Instant Messaging	23	1.96	1.022

[a] for a 5-point Likert-type scale from 1=unutilized... to 5=very helpful

Table 4.6

Descriptive statistics for channel variables - site supervision personnel case 2

Variable	Respondents	Mean[a]	Standard Deviation
Face-to-face meeting	21	4.48	1.030
Telephone	22	4.18	0.958
Email	22	3.55	1.057
Text Message	22	2.82	1.097
Videoconferencing	22	2.41	1.532
Online Instant Messaging	22	1.86	1.167

[a] for a 5-point Likert-type scale from 1=unutilized... to 5=very helpful

In order to understand if these preferences are similar to general professional preferences and personal preferences, the researcher performed a series of pairwise comparisons at the $\alpha = 0.05$ level. First, personal and professional preferences were compared for both roles. No significant differences were found in face-to-face ($\rho = 0.144$) and telephone ($\rho = 0.360$). In contrast, significant differences were found in email ($\rho < 0.000$), text messaging ($\rho < 0.000$), videoconferencing ($\rho = 0.005$), and online instant messaging ($\rho = 0.001$).

Next, the first case for designers and site supervision personnel was compared to professional general preferences. For designers, research results indicated no significant differences for face-to-face ($\rho = 0.081$), telephone ($\rho = 0.171$), text messaging ($\rho = 0.180$), videoconferencing ($\rho = 0.204$), or online instant messaging ($\rho = 0.705$), though significant difference was found for the use of email ($\rho = 0.015$). Similar results were found for site supervision personnel, in which no significant differences were found in face-to-face ($\rho = 0.260$), telephone ($\rho = 0.083$), text messaging ($\rho = 0.206$), and online instant messaging ($\rho = 0.564$), though, again, significant difference was found for email ($\rho = 0.034$).

Following descriptive statistics and pairwise comparison of personal and professional preferences, the researcher has independently performed repeated measures ANOVA for both roles and cases related to channel differences at the $\alpha = 0.05$ level. Hypotheses for both roles are presented below:

> H_0 = *there is no significant difference between channels regarding helpfulness for design problems*
>
> H_a = *there is a significant difference between channels regarding helpfulness for design problems*

For designers in cases 1 and 2, the null hypothesis was rejected (case 1 F=20.536 and $\rho < 0.000$; designers' case 2 F=32.322 and $\rho < 0.000$). The same was true for site supervision personnel (case 1 F=21.571 and $\rho < 0.000$; designers' case 2 F=21.264 and $\rho = 0.000$).

Because significant differences were found in the repeated measures ANOVAs, pairwise comparisons were made, generating line plots for all four tests. Line plots identify the groups to which each channel belongs. Channels in the same group do not present significant differences at the $\alpha = 0.05$ level with a Bonferroni adjustment and are represented with the same letter. Tables 4.7 and 4.8 present the findings, with each case as a separate column.

Table 4.7
Lines plot for channel variables - design personnel case 1 n=26, and case 2 n=26

Variable	Group Case 1		Group Case 2			
Face-to-face meeting	A		A			
Telephone	A		A			
Email	A		A	B		
Text Message		B		B	C	
Videoconferencing		B			C	D
Online Instant Messaging		B				D

Table 4.8
Lines plot for channel variables - site supervision case 1 n=23, and case 2 n=21

Variable	Group Case 1		Group Case 2			
Telephone	A		A			
Face-to-face meeting	A		A	B		
Email	A			B	C	
Text Message		B			C	
Videoconferencing		B			C	D
Online Instant Messaging		B				D

After the repeated ANOVAs, the researcher analyzed the ranking questions in the survey. Descriptive results are presented in tables 4.9 through 4.12.

Table 4.9

Descriptive statistics for ranking of channel variables - design personnel case 1

Variable	Respondents	Mean[a]	Standard Deviation
Face-to-face meeting	28	1.57	1.034
Telephone	28	2.25	0.928
Email	28	2.96	0.922
Videoconferencing	28	4.04	1.374
Text Message	28	4.39	0.994
Online Instant Messaging	28	5.79	0.418

[a] the ranking system considered 1=most helpful... to 6=least helpful

Table 4.10

Descriptive statistics for ranking of channel variables - design personnel case 2

Variable	Respondents	Mean[a]	Standard Deviation
Telephone	26	1.81	0.895
Face-to-face meeting	26	2.08	1.262
Email	26	3.04	0.824
Text Message	26	4.08	1.164
Videoconferencing	26	4.38	1.388
Online Instant Messaging	26	5.62	0.852

[a] the ranking system considered 1=most helpful... to 6=least helpful

Table 4.11

Descriptive statistics for ranking of channel variables - site supervision case 1

Variable	Respondents	Mean[a]	Standard Deviation
Face-to-face meeting	20	1.45	0.999
Telephone	20	2.60	1.392
Email	20	3.00	0.649
Videoconferencing	20	3.95	1.432
Text Message	20	4.35	1.137
Online Instant Messaging	20	5.65	0.587

[a] the ranking system considered 1=most helpful... to 6=least helpful

Table 4.12

Descriptive statistics for ranking of channel variables - site supervision case 2

Variable	Respondents	Mean[a]	Standard Deviation
Face-to-face meeting	18	1.78	1.114
Telephone	18	1.94	0.938
Email	18	3.17	0.857
Text Message	18	4.00	0.907
Videoconferencing	18	4.28	1.487
Online Instant Messaging	18	5.83	0.383

[a] the ranking system considered 1=most helpful... to 6=least helpful

Friedman tests were performed on the ranking questions. Friedman test hypotheses for designers and site supervision personnel are presented in the following equations:

H_0 = *there is no significant difference between channels regarding helpfulness for design problems*

H_a = *there is a significant difference between channels regarding helpfulness for design problems*

All Friedman tests for designers and site supervision personnel in case 1 and case 2 were significant at the 5% level ($\rho < 0.000$). Further, post-hoc Wilcoxon pairwise tests were performed. No adjustment to the significance level was made due to the conservative nature of the Wilcoxon test. Line plots were produced to illustrate differences or similarities between channels. Channels in the same group do not present significant differences at the $\alpha = 0.05$ level and are represented by the same letter. Tables 4.13 and 4.14 present the findings.

Table 4.13
Lines plot for channel variables - design case 1 n=28 and case 2 n=26

Variable	Group case 1	Group case 2
Telephone	A	A
Face-to-face meeting	A	A
Email	B	B
Videoconferencing	C	C
Text Message	C	C
Online Instant Messaging	D	D

Table 4.14

Lines plot for channel variables - site supervision case 1 n=20 and case 2 n=18

Variable	Group case 1				Group case 2			
Face-to-face meeting	A				A			
Telephone	A	B			A			
Email		B				B		
Videoconferencing			C				C	
Text Message			C				C	
Online Instant Messaging				D				D

The results from the Wilcoxon pairwise comparison indicate a clear division between the top three most helpful channels and the bottom three least helpful channels. It also indicates clearly that there are no significant differences between a face-to-face meeting and telephone, and between videoconferencing and text messaging.

Results from the repeated measures ANOVAs and Friedman tests, along with the post-hoc pairwise analysis for both, indicate that there are significant differences between certain communication channels. Results indicate clearly that the top two most helpful channels are face-to-face meeting and telephone. Email seems to follow as a third most helpful channel, although some post-hoc ANOVA tests indicate no significant differences between email and text, and between email and videoconferencing. All Friedman tests indicate a clear separation between the top three most helpful and the bottom three most helpful (text message, videoconferencing, and online instant messaging).

Therefore, in order to answer research question one, the researcher has established a ranking of most helpful channels for design problems in a design and site supervision interaction setting, presented in table 4.15. In this table, one is the most helpful channel and six is the least helpful channel.

Table 4.15
Most helpful channels for design problems necessitating urgent site supervision and design interaction

Variable	Ranking[a]
Face-to-face meeting	1
Telephone	1
Email	3
Text Message	4
Videoconferencing	4
Online Instant Messaging	6

[a] the ranking system considered 1=most helpful... to 6=least helpful

4.1.3 Qualitative contributions

Participants in phase 1 were invited to provide more details regarding the choice of most helpful channels in each case. Nine site supervision personnel made comments regarding their choices for channel in case one and three chose to do so for case two. Fifteen design personnel made comments regarding their specific case one choices and ten chose to do so for case two.

Findings from case one for site supervision personnel indicate telephone and face-to-face as the most helpful channel due to immediateness of response and the possibility of suggesting solutions. One respondent said, "Face-to-face is always better in my opinion. It's easier for the architect or designer to see what went wrong rather than imagine it from the supervisor's description." Another participant also shares a face-to-face preference: "Nothing beats face-to-face interaction when trying to solve a problem."

On the other hand, some respondents indicated that even though face-to-face is the most helpful, they are rarely given that option because the designer is not on site. Only two respondents indicated the use of text messages. One user explained:

"For an issue needing immediate resolution, telephone, combined with SMS photos of site conditions or sketches, is the quickest. Face-to-face is helpful, but designers are rarely on site."

One respondent indicated that they always try to use email, and if telephone or face-to-face meetings are used, a follow up email is sent after in order to create a 'paper trail.'

> We try to use email as much as possible in order to keep a paper trail of quick decisions so that they are easily tracked, but sometimes that is not always an option since people do not hover on their email all day. Phone calls and face-to-face meetings are the quickest ways to get answers, but we need to make sure we follow up with an email to track changes.

Only three respondents made comments in case 2 for site supervision personnel. Only one mentioned the name of one of the channels, one indicated that the response given before applies to this case ("Same comments as previous page."), and one indicated preferences for phone, email, and text due to design personnel's current availability and technology availability. The same respondent indicated that "face-to-face & video conferencing require coordination and increased availability."

As mentioned previously, design respondents provided more comments for their specific cases. Many respondents indicated being away from the site: "Face-to-face is always the best form of communication but it takes time when your projects are spread out all over the place." Therefore, some participants justified using the phone as a primary means of contact: "Due to distance and working in different regions, telephone is the quickest for me - especially when on the road."

Video conferencing was mentioned by four of them. Two of them indicated this would be a good channel, but three indicated that the main reason why this channel is not more frequently used is access and usability. One participant explains: "Text, IM, and Videoconferencing are not handy when traveling and are inefficient when at the office." Another indicates a technology gap between them and personnel on site: “Field staff usually don’t have access to video conferencing; field guys typically don’t text.” One participant mentions, “We don’t have the capabilities to video conference. I’d imagine that it would be very helpful.”

Face-to-face interaction is still indicated as the most helpful form of communication in case of design problems due to the possibility of immediate feedback and the availability of a shared problem space. This was explained by a participant: “There is no substitute for seeing the problem in context and evaluating options with a contractor.” Another participant mentions face-to-face as a way to decrease assumptions they work with: “Any methods besides face-to-face may increase the chances for assumptions, which may lead you to the wrong answer or conclusion.” One other participant explained how visuals provided through face-to-face interaction help communication: “Face-to-face, as one can use gestures to help describe 3-D issues. Videoconferencing would be helpful for the same reason. Telephone is good because you are talking, and e-mail is good. I still like faxes because one can draw pictures rapidly. A picture is worth a 1000 words.”

Similar answers were provided in case 2. Two respondents indicated that videoconferencing would be helpful, but availability of that technology for both parties is an issue. One respondent justifies his choices with the following comment: “3-D drawings would be ideal if both parties used them. I would want to go to the site to meet with the Site Supervisor directly and see changes in the field.” Also, telephone and face-to-face seem to be used as a combination in order to combine agility of the phone with accuracy of face-to-face, as one participant explained: “If it is something that needs a possible design change, seeing it in the field is most helpful, after being alerted by phone.”

Information provided by respondents added value to the qualitative analysis. The information given by interviewees indicated issues influencing choice of media, such as physical distance between stakeholders, liability and risk management, and need of accuracy in problem description. Respondents also indicated that normally more than one means of communication is used in order to combine the advantages and reduce the disadvantages of each of them.

4.1.4 Discussion

Results presented in phase one are consistent with those indicated by Media Richness Theory researchers (Daft et al., 1987). Reasons that explain participants' choice of channels are also consistent with MRT, as qualitative answers indicate that some respondents are aware of the possibility of face-to-face providing more cues than other media as well as immediacy of feedback. In their study, Daft et al. (1987) indicated that face-to-face is the richest media, followed by telephone, then email, and finally written report. Some of the qualitative input provide by respondents clearly refer to the existence of gestures in face-to-face communication that might not be available when using other means, and as well as to the need for making assumptions to fill message gaps when not face-to-face.

Similar findings regarding face-to-face meetings were obtained by Emmitt and Gorse (2003) and Fox et al. (2010). In their research, Emmitt and Gorse (2003) found that face-to-face is the most helpful means of communication in the construction industry. Out of the eight means of communication researched, telephone communication was voted fourth. In between telephone and face-to-face, findings show written communications (email or faxes) with drawings. It is important to note that Emmitt and Gorse (2003) researched construction communication as a whole and not specific design problems in an urgent setting. On the other hand, the study conducted by Fox et al. (2010) indicates synchronicity as important for construction communications.

Results obtained in the present study also indicate that no significant difference at the $\alpha = 0.05$ level was found between site supervision and design personnel. Limitations to this finding apply, as cases were slightly different by role. Emmitt and Gorse (2003) indicate that they also have found no difference between contractors and architects regarding face-to-face preferences in their study. However, Emmitt and Gorse (2003) indicate that they found architects and contractors to have differing preferences regarding the use of telephone and email communications. Emmitt and Gorse (2003) researched overall construction communication in their study.

Constraints indicated by qualitative data such as liability issues and physical distance are also consistent with the specific context of construction. The industry is highly fragmented between multiple stakeholders who join efforts in building an unique product (Cheung et al., 2013; Dave & Koskela, 2009; Emmitt & Gorse, 2003). This product is often built on a remote location from the design office. The need for a 'paper trail' confirms the lack of trust in the industry, as mentioned by researchers (Cheung et al., 2013; Fox et al., 2010; Nesan, 2012). This is a consideration while choosing means of communication in the AECO industry.

The low rate of adoption of technology has been previously mentioned by researchers (Ibem & Laryea, 2014). Therefore, it was not unexpected that newer technologies such as videoconferencing, text message, and online instant messaging were not mentioned by respondents as being as helpful as more traditional channels (face-to-face, telephone, and email). However, it is interesting to note that there seems to be a high standard deviation in results for text message and videoconferencing, as well as qualitative inputs from respondents suggesting that changes may come in the near future as accessibility to those channels increases.

Regarding gender issues, the present research has an unbalance between male and female respondents. Considering designers and site supervision personnel combined, only 23% were females (77% males). This rate is consistent with 25% of females working in architectural services (except naval) but is much higher than the 12% of females working in the construction industry, according to the US Bureau of Labor Statistics (2014) report.

Although literature indicates differences in communication patterns between males and females (Adrianson, 2001; Ng & Byra, 2006), the present survey did not indicate significant statistical differences between choices made by males and females regarding communication channels for design issues. The researcher hypothesizes that the urgent characteristics of the problem overshadows gender differences that may exist; however, further studies would provide more information to explain results found in this present research.

Due to the small number of respondents under the age of 30, it was not possible to perform a statistical analysis to assess age differences. However, the researcher performed statistical analysis regarding channel preferences for professional and personal communication of respondents for phase 1 and found that there are significant differences in four (email, videoconferencing, text messaging, and online instant messaging) of the six communication channels surveyed. This is consistent with Kurkovsky and Syta (2010) and Friedl and Verčič (2011), who mentioned that even though new communication technology is available, millennials still prefer to use more established channels in a work setting.

As for specific work preferences, the analysis of rankings for specific design issues and general issues for both designers and site supervision personnel indicated no significant statistical differences at the $\alpha = 0.05$ level for five out of the six channels surveyed. The only channel with statistical difference for both designers and site supervision personnel was email. In both cases, the groups indicated email as being significantly more helpful for design issues. Future research could provide a clearer explanation, but comments made by respondents indicating the importance of keeping a 'paper trail' of communication suggest that the influence of liability concerns may play a role in this difference.

4.2 Phase 2 - Interviews

Phase two of this study consisted of eight semi-structured interviews with AECO industry professionals. Appendix B contains the questions asked to subjects during the interviews. For this phase, the researcher will present sample demographics, a summary of normal work processes of participants and a summary of design problem-solving inputs. More in-depth analysis will be provided for advantages and disadvantages of communication channels used, with a special focus on face-to-face, telephone, and email.

Participants of phase one (online questionnaire) were asked if they would like to provide more information through an later interview. Two volunteers were obtained using phase one contacts. Three were obtained through contacts made during the Fall 2015 Building Construction Management (BCM) Career Fair at Purdue University. Another three were obtained by sending invitation emails to 200 design companies. Interviews were conducted between the months of September and November of 2015.

Duration of interviews ranged from 25 to 47 minutes, with a mean of 35.8 minutes and a median of 35.5 minutes. Interviews were audio recorded and transcribed by the researcher. Transcripts were uploaded in NVivo for analysis.

Transcribed text was coded according to the pre-selected category codes: channels, common design problems, lessons learned, and problem solving strategies. The channels category was expanded into more specific in-category codes generated by the primary researcher after analyzing data independently. The sub-codes include: advantages, disadvantages, email, face-to-face, file transfer protocol (FTP) or dropbox, Online Instant Messaging, Online software management system, radio, telephone, text message, and videoconferencing.

All nodes and sub-nodes developed were then used to code the anonymized transcripts. Coding was performed by the primary researcher with the help of an assistant researcher. The researchers discussed the data, and coding was done based on consensus. Saldaña (2009) indicates that this collaborative approach is a way to enrich the analysis by discussing different points of view about the data.

The following subsections will present the reader with a description of sample demographics and then a summary of findings regarding normal work processes and general problem solving. Finally, the researcher will present analysis regarding design problem-solving in construction, as well as advantages and disadvantages of communication channels for design problems.

4.2.1 Sample demographics

Interviews were conducted with eight participants: four from the design side and four from the site supervision side of construction. Current work location varied, with three participants coming from the East North Central Region (IL, IN, MI, OH, WI), two participants from the South Atlantic Region (DC, DE, FL, GA, MD, NC, SC, WV), two from West South Central Region (AR, LA, OK, TX), and one participant from an undisclosed location (by request of the participant).

Size of companies varied. Two participants came from companies that have between 1 and 9 employees, two participants from ones that have between 50 and 249 employees, three from companies having between 250 and 999, and one with a company employing more than 5,000 employees. Most companies performed several different types of construction, with exception of Heavy Civil, which only one

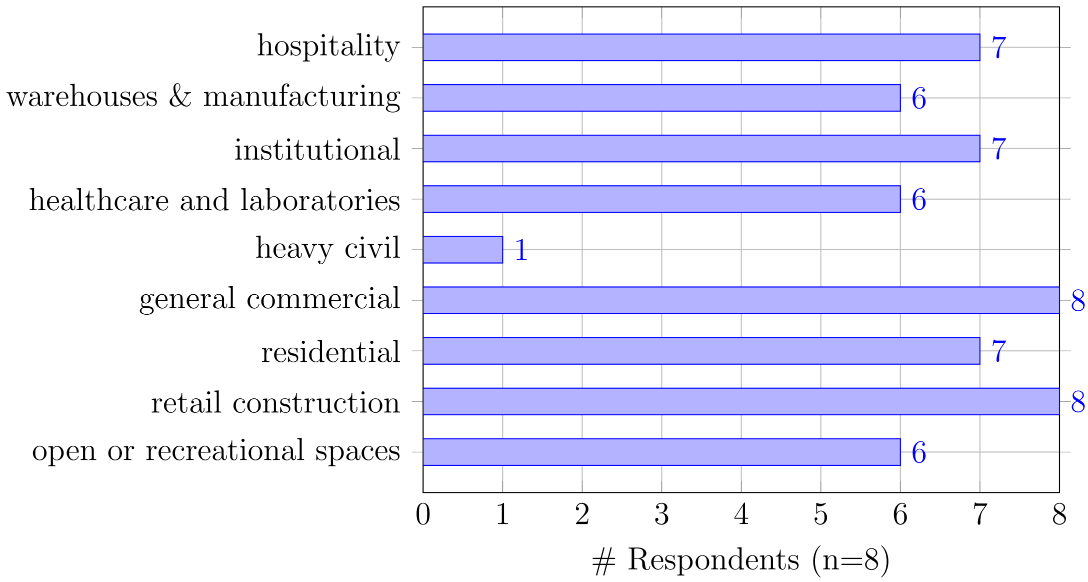


Figure 4.4. Type of construction performed by participants' companies

participant mentioned as part of the company portfolio of work. Figure 4.4 presents the breakdown of construction-type of the interviewee' companies.

Years of full-time experience of interviewees ranged from 3 to 36 years, with a mean of 17.75 and a median of 18.5. As for participants' age, one participant was in the 25 to 29-year range, two were in the 30 to 39 range, four were between 40 to 49, and one was between 50 and 59 years old. Only one of the eight interviewees was female.

Five participants stated that they have a college degree, and three had a master's degree. Four had their construction degrees in construction management programs, two in architecture program, one in architectural engineering, and one in computer graphics design.

4.2.2 Summarized findings for routine work processes and general problem solving

The interview was separated into four parts: normal work routine, general problem solving, design problem solving, and demographics. In this session, summarized findings for normal work routine and general problem-solving skills of interviewees will be presented. This provides more information about processes and routines that may affect design problem solving.

4.2.2.1. Normal work routine summarized findings

The job titles of interviewees varied. Design personnel were either design or project managers (3) or architectural designer (1). Construction management personnel were assistant project managers or project managers (2), project engineer (1), or vice-president (1). Participants indicated that they had worked at their present company from 1 to 18 years.

Normal work processes reported by interviewees varied by title and by discipline but presented similarities as well. Design related professionals would dedicate part of their time to designing or reviewing design documents, managing design schedules, and answering RFIs, and management professionals would mostly focus on personnel management and look-ahead planning, as well as performing constructability and price reviews and dealing with conflict resolution. Most interviewees also reported regular participation in meetings, especially those related to site construction or those from the design side that were on-site. Management of email communication was also mentioned by all interviewees as an important aspect of their regular work processes. Two interviewees (one from the site supervision side and one from the design side) mentioned the lack of a work routine due to daily revision of priorities or emergency situations.

Information from contractors or designers was most often received using online project management software in case of documents, but such exchanges also took place through emails or file transfer protocol (ftp) websites. Most online project management software tools also use email to alert users about updates on projects and are used by all designers, contractors and subcontractors involved in the project. These tools also include management of other construction related information and documentation, such as requests for information (RFIs). Examples of utilized softwares cited by interviewees were: PMweb, Submittal Exchange, and Procore.

Interviewees mentioned that communication between design and site supervision personnel varied with job complexity, schedule, and size. Information exchange increases with higher complexity, fast track construction, or projects that are great in size. It was also noted by one interviewee that an indication of job complexity is the amount of specialized parties working on the project. The interviewee mentioned: "...the more that these [building] components segregate and become complex, the more problems happen, because there are a lot of teams involved...there is a big web...there are expertise, and with people with expertise involved you need to understand the perspective of each one of these parties and try to facilitate information [exchange]."

Both the construction management and design side mentioned site visits as important moments for design clarifications. Again, the number of site visits may differ depending on site complexity, from as little as once every two weeks to, in some cases, having an assigned design personnel on site to clarify design issues at all times. This was the case of one design manager and two site supervision personnel, who mentioned they had an on-site design personnel to clarify design issues.

Examples of regular communication between designers and field personnel include RFI responses, site directives, and design clarification. Examples of communications moving from contractors to designers include mainly RFIs and submittals. These communications may be done during site visits but also through email or telephone.

4.2.2.2. General problem-solving summarized findings

Interviewees mentioned that they have to deal with unexpected problems not exclusively related to design from daily (most frequent) to once a week (least frequent). Again, this seems to be related to complexity, size, and schedule of project, as one interviewee elaborated on the reasons for problems to arise: “It really depends on the complexity of the project. And the size of the project.” Half of interviewees mentioned that they encounter unexpected problems every day. Some issues interviewees faced recently included staffing projects, scheduling, logistics, contract management, and software troubleshooting issues. All of the interviewees who described specific problems mentioned the need to communicate with other people in order to find solutions.

As cited by interviewees, the media most often used to coordinate unexpected general issues that arise are face-to-face, email, and phone. Usually face-to-face is preferred if all involved personnel are available. If it is an urgent issue, phone is mostly used. Email is seen as more convenient when communication is not urgent or if there is a need for a recorded document of the conversation, such as it is mentioned by one interviewee: "And I follow up with an email with 'here's what we talked about'." Also, one interviewee mentioned that he preferred email communication due to working in a different time zone from the headquarters. Choice of media in these cases seemed to vary greatly according to each situation. Only one interviewee mentioned using an online instant messaging application to discuss in-office issues with team members.

All construction managers mentioned that they have learned from the issues they have faced and would probably change their approach the next time a similar issue happened on site. As for designers, most managerial or logistical problems mentioned dealt with routine problems such as staffing projects and software troubleshooting. No specific lessons learned were discussed by designers during interviews.

4.2.3 Design problem solving and communication channels

There was a significant difference between designers and site supervision personnel regarding how often they faced problems related to design in their work. While construction managers indicated having a range of four problems per week to problems every day, designers indicated that they deal with problems related to design between twice per week and twice per month. The number of problems reported to be urgent also differed between each group of interviewees, while designers reported having less urgent problems. One designer mentioned that they normally are given a week between receiving the problem and coming up with a solution. Another designer reported that only 60-70% of the problems were actually urgent: "And what happens is that usually if we first get contacted, the field personal like always thinks its urgent 100% of the time. And many many times it is. But then, as we dig deeper, we realize while it's urgent and it needs to be addressed, it also might be that it is not as urgent that we can't take a little time to research and talk to the owner, and learn them into the conversation."

Construction managers varied their responses when asked how many of the design problems are urgent. The range varied from 10% to 85-90%. Interviewees mentioned that this varies greatly with the construction schedule, meaning that the closer to completion, the more urgent the problems become. One interviewee also mentioned that fast track construction also influences the amount of urgent design problems they have as a company.

Some common issues reported by interviewees relating to design issues are:

- Problems related to incompatibility between design disciplines (for example, between architectural and structural drawings or between structural and electrical layout, mechanical ducts, plumbing pipes, or beam clashes in ceilings);
- Construction drawings do not have enough details or information;
- Constructability issues (for example designer placing a structure on top of a slab without considering structural repercussions)
- Accuracy of drawings in the case of renovations and demolitions

All respondents indicate the need to interact with their team and other stakeholders to solve these issues. In these cases, face-to-face, email, and telephone were all mentioned by interviewees as means of communication to solve the problem. Usually when solved face-to-face or over the phone, an email would follow to formalize previous communication. Face-to-face was indicated by participants as the preferred method, if stakeholders were available. One participant mentioned doing most site work in a different state than the architect and client. In cases of problems, a conference call would be arranged, and after that follow up emails containing drawings would be exchanged until a solution was found.

Some of the problem-solving strategies mentioned by interviewees were:

- On-site design team (if given authority) can issue site directives so that work can proceed without delay;
- Site team talks with own team to propose solution to the problem prior to engaging with designers;
- Design and site teams talk to each other and to other stakeholders involved in the issue;
- Identify the stakeholders involved in issue and understand who are the decision makers for the problem;
- Use adequate means of communication available for each contact;
- Re-evaluate means of communication in case there is no advance in resolution or in case of miscommunications;
- Regularly scheduled site walks by the architect;
- If final solution takes too long, re-think schedule and order of work so that construction does not stop

When asked about the most helpful channels to use in these situations, interviewees mentioned a combination of face-to-face, email, and telephone. Again, face-to-face, when that is a possibility, was indicated as being the most effective by most participants. However, one participant mentioned that if the right person is not available on site, meaning a person who understands the design concept and is capable of making decisions, then they would rather contact an off-site person. One interviewee also mentioned using videoconferencing to show designers the situation on site so that they can better discuss issues that arise. One respondent indicated that the choice of media depends on problem specifics and that face-to-face, email, and phone all have advantages and disadvantages.

All interviewees mentioned that at some point in their careers, they have experienced a moment when they had to change channels because communication was ineffective. These changes were mainly from email to phone (5), or email to face-to-face (2), phone to email (1). One participant gave two answers to this question and one did not answer this question directly.

All respondents agree to the fact that face-to-face, email, and telephone accurately reflect the main media they use to communicate between design and site supervision personnel regarding design problems. However, three mentioned that they would place them in a different order, with email in second place and phone in third. One ranked them as telephone, email, and then face-to-face; this participant indicated that his choice was based on the fact that most of his work happens on places the architect or owner would not able to visit frequently. One other participant ranked the communication choices as face-to-face, telephone, videoconferencing, and then email.

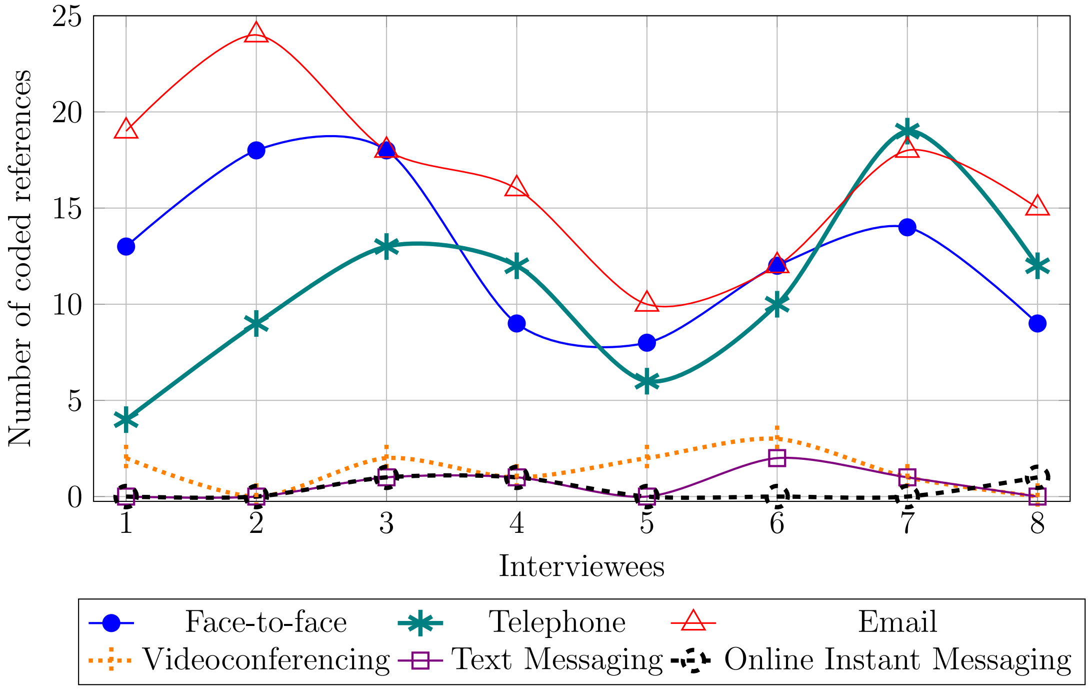


Figure 4.5. Frequency of channels mentioned by interviewees

Figure 4.5 indicates the frequency with which each interviewee mentioned each of the six channels: face-to-face, telephone, email, videoconferencing, text messaging, and online instant messaging. It is important to note that the four final interview questions specifically mentioned face-to-face, telephone, and email, which influenced the frequency interviewees mentioned those channels.

4.2.3.1. Communication Channels Advantages and Disadvantages

Interview responses were coded by two coders who worked together until a consensus was reached to identify advantages and disadvantages of the most frequently used communication media: face-to-face, telephone, and email. Coded text was analyzed by the author to select the main advantages and disadvantages of each of the communication media studied in this phase.

First, word clouds for the codes channel, face-to-face, telephone, and email were generated by the researcher using the 500 most frequent words. Synonym words were grouped together. In a word cloud, the size of the word is a representation of how frequently that word (or related words) is mentioned. Figure 4.6 presents the word cloud for channels. In this figure, one can observe that the most frequent words cited are related to 'telephone' and 'email.' Face-to-face is also frequently mentioned, though less than the aforementioned two. This may suggest that telephone and email use in construction are complementary. This also seems to reflect that availability may also play a role in frequency, since those same interviewees all indicate face-to-face as being the most helpful way of solving urgent design problems in construction.

Separate word clouds were generated for each of the main three communication media and are presented in figure 4.7. Again, 'phone' and 'email' appeared greater in size than other words for codes phone and email, indicating that both channels were frequently cited together. For face-to-face, the 'face-to-face' word appeared larger in size than others, but close to 'phone'; 'email' appeared

Figure 4.6. Word Cloud for the Code Channels

smaller than the two aforementioned communication media, and therefore was less frequently mentioned by interviewees.

Figure 4.7. Word Cloud for the Code Face-to-Face (left), Phone (center), and Email (right)

Through the word clouds, the researcher confirms the usage of all three means of communication to solve problems in construction. Interviewees indicated that the choice between the three depends upon (1) availability of all parties involved in the issue, (2) urgency of issue, (3) information to be conveyed, and (4) need to formalize communication in writing.

Nevertheless, all but one interviewee mentioned face-to-face as the most helpful for solving design problems in an urgent situation. Five of them indicated that they need to take into account the availability of designers to go to the site. One interviewee mentioned coordination of schedules to meet at the to site as a problematic task: "Just coordinating peoples' schedules to actually meet, depending on how many are involved, that seems to be a huge issue nowadays, more than ever." Another interviewee from the design side indicates that "…if the site is convenient enough I would run out there or ask somebody from the office to go there and take a look to make sure that we understand what the problem is…and what they are talking about."

When talking about channel selection, interviewees mentioned that they would make different channel selections based on the urgency of the issue. For urgent issues, one interviewee indicates face-to-face as a way to avoid delays: "…when it's a face-to-face, it's because it's an urgent issue. I don't have time to go back and forth with email." Another participant indicated the the phone can be used to convey an urgent tone to the person on the other end of the line: "the phone calls were probably more beneficial because you can kind of…they can hear in your voice, you know how urgent it is, as opposed to sending an email."

Another basis of selection frequently mentioned by interviewees was the information to be conveyed. The discussion of visuals such as drawings or colors highly influences the decision to use channels that support visual aids, such as face-to-face or email. One participant explained this issue: "…and there is no visual aid with the phone. If you have a phone to work an issue you may have to supplement it with an email where you send a markup drawing, or go to meeting where you are sharing your screen." The rationale for choosing a channel based on information to be conveyed does not apply only to visual information but also to conveying some managerial decisions. One interviewee mentioned, "If it's a problem that you need to rip somebody down, then yes, [face-to-face] is a disadvantage... I would prefer doing it by email." Interviewees indicated that controversial issues that may generate adverse emotional reactions influenced their choice of channel.

Finally, it was indicated by seven out of eight participants that the need for written documentation also affects their choice of communication channel. One participant mentions the use of phone for informal conversations: "I like to use the telephone when, once again, I want to talk to the contractor in person and not have... when I want to ask them their opinion [...] In other words, when I have something and I don't want to make it through an official channel." However, it has been indicated in interviews that most of communications, regardless of the channel used, will need written documentation. One participant mentioned this as a result of the legal environment for the AECO industry in the US: "... the US is a very litigious environment. Everything has to be on 'paper,' so I would not give that much credit to a phone call unless there is an email following up."

After a qualitative analysis of the reasons behind selection of communication channels, the researcher analyzed the codes (face-to-face, telephone, and email) as they connected to the codes (advantages and disadvantages) created in the analysis. The summary for advantages and disadvantages of each channel are presented in table 4.16 on the following page. This the main outcome of phase two of this dissertation, answering research question 1b ('What are the advantages and disadvantages of each of the most used media?').

Table 4.16

Channel advantages and disadvantages for design problem-solving in construction

Face-to-face	
Advantages	**Disadvantages**
Richer channel (may use tone of voice and other visual aids);	Potential emotional interactions in meetings may be undesirable;
Synchronous (quicker answers);	Schedule availability;
Allows for timely emotional support if needed (more personal);	Lack of written record (if there are no minutes);
Reduced message ambiguity.	May not allow time for thorough reflection.
Telephone	
Advantages	**Disadvantages**
Synchronous (quicker answers);	Depends on receiver's availability;
Rich channel (tone of voice);	No written record;
Good for informal conversations;	Difficult to convey visual information;
Good to convey urgency.	May be disruptive to work.
Email	
Advantages	**Disadvantages**
Does not depend on receiver's availability;	Impersonal, may lead to misunderstandings;
Written record;	Email overload;
Less charged with emotions;	Writing effective emails may take time;
Allows visual aid attachments;	Less effective to older generations.
May be accessed through several different gadgets;	Asynchronous (may cause delays in communication);
Allows time for reflection.	

In several questions, interviewees mentioned some channels characteristics as beneficial at times and prejudicial at other times. Four interviewees mentioned as a disadvantage the emotional content in face-to-face encounters. However, one of them indicated that this can also be an advantage sometimes: "I would say that a lot of times a face-to-face meeting can really help out a lot of things. It can calm people down because you've got a face to the people in front of you. And you have to sort of interact in a socially acceptable manner... And it's also easier to back and forth and also to have that facial expression cue and whatnot. However, in some cases that can also escalate tensions if you are not careful..." Relatedness of advantage and disadvantage was also mentioned for the absence of written record of telephone conversations. In the case of telephone, interviewees mentioned that in some situations it is beneficial to have an informal conversation, without written record. However, most interviewees mentioned the lack of written record as a disadvantage of using the phone.

Interviews indicated that all the main media channels are complementary to each other. One interviewee noted that he would start to discuss a problem over the phone "to explain the problem, and it would be in a conference phone to discuss the problem. And then, in the coming days, even a week after that, most communications were done via email. Drawing changes and stuff like that." So conversations would advance later in emails with visual-aid attachments. Interviewees also mentioned that communication sometimes happened the other way around, where emails were sent but the responses obtained were unclear or insufficient, and so then another communication channel would be used: "...if my initial channel was email and it was not responded to in an efficient manner, then I would call for a face-to-face conference or phone call."

Most interviewees also indicated that emails were used as the final communication channel after face-to-face or phone conversations as a way to record those interactions: "I do like using email a lot for documentation. [...] Even after a face-to-face meeting, I'd sometimes send out an email to document what we talked about." This was mentioned by another interviewee when questioned about the primary interaction between site supervision and design team: "[Phone] is usually the initial item. And it might be followed up, if the owner gets involved, with an email. Documenting... actually having documentation, because the phone is not very good for that. And the phone call is just usually the kick off... you know, very often it might start my research, or it might facilitate a site meeting, you know, do a face-to-face."

During the interviews, some participants briefly mentioned using other media. Two interviewees mentioned using file transfer protocol (ftp) for the exchange of technical information consisting of mainly drawings, especially due to the large file size. Texting was mentioned by three interviewees, but only for brief communications. One interviewee mentions that "... the only time I would text my designers would be like: 'Hey, I'm in a meeting. I'll call you right back.' If they are trying to get a hold of me. But it is not for coordination purposes. It's more like giving a heads up. 'Hey, I'm not available right now."'

One interviewee who works on site brought up the use of radio for communicating with his personnel on site. Also, only two interviewees mentioned using online instant messaging. One of them mentioned using that channel for brief question-and-answer types of communication, and another interviewee talked about using this channel for team communications in the office.

Four interviewees indicated that they used videoconferencing with other stakeholders in the project, although not as frequently as face-to-face, telephone, and email communication. The main advantage of this, as mentioned by interviewees, was the ability to share their screen and show the other party a specific part of a drawing. One interviewee described the process: "... like a 'Skype' call and with a shared monitor we start to look together at the drawing and pointing to these issues, so the two parties are on the same page." The advantage of all parties being able to look at the same information was indicated explicitly by those four interviewees.

4.2.4 Discussion

All interviewees from the construction side mentioned having learned from the problems they have faced on site. If given the same situation, they said they would probably change their approach. This is consistent with the high importance of tacit information and experience in the construction industry (Dave & Koskela, 2009; Gacasan, Wiggins, & Searle, 2016; Nesan, 2012). Even though participants put heavy emphasis on obtaining written documentation of decisions, they also mentioned that sometimes an informal conversation was helpful in order to discuss possible courses of action. These informal conversations are often not recorded, which confirms the tacit nature of the construction industry.

Additionally, even though information exchanged in email is considered to be 'formal' by interviewees, research indicates that this type of tool "...may have negative impact on organisation's knowledge management capabilities. This is due to the fact that such tools cause information overload due to unorganized and ad-hoc information exchange"(Dave & Koskela, 2009, p. 896). This is also consistent with findings from this dissertation, as one interviewee explains this concern: "So I think there is an over-inundation of email. I think that somehow that needs to change...I don't really know how you fix that because it's part of their record-keeping process, you know."

The need for record keeping was mentioned as extremely important in this industry, which is also mentioned by previous authors who have discussed liability issues in construction (Levin, 1998; Schoenwetter & Carver, 2008). Two factors mentioned by participants that increase project complexity were industry fragmentation and fast-tracking projects. Project fragmentation is characteristic of the AEC industry, as construction of a building requires the participation of several parties. Often these parties need to collaborate and coordinate their plans of action in order to advance work as a whole (Chan & Sher, 2014; Dave & Koskela, 2009; Emmitt & Gorse, 2003; Gacasan et al., 2016). The greater the number of companies and professionals involved in the process, the more complex the project, since coordination needs to increase. The other reason for project complexity is fast-tracking. Burr and Jones (2010) mentions that fast-track construction also requires the integration of many disciplines as construction may start without the complete set of drawings first being concluded.

This phase also confirmed the preference for richer means of communication to convey important messages. Reasons for the choice of richer means of communication also are aligned with research on Media Richness Theory (MRT). In MRT, richness is based on the possibility of immediate feedback, multiple cues, language variety, and personal focus (Daft et al., 1987; Straus, 1997). However, interviewees mentioned that the availability of the channel to all parties who are sending and receiving the message also is an important base for selection. This is especially important in construction, where most of the construction activity happens on-site while designers are often in the office, in a location away from the construction. Webster and Trevino (1995) indicate that this is a situational factor that may influence the choice of media for communication. Therefore, even though they consider face-to-face to be the most helpful, situational constraints may influence professionals to use other communication channels that are not as rich.

On the other hand, when questioned about their own rankings of channel helpfulness, interviewees did not always mention the order of most to least helpful as face-to-face, telephone, and then to email, as it was reported by Webster and Trevino (1995) and Daft et al. (1987). Media Richness Theory has suffered criticism to for showing inconsistent findings when applied to computer-mediated communication (Otondo et al., 2008; Palvia, Pinjani, Cannoy, & Jacks, 2011). Several interviewees mentioned that email attachments conveying design information is an essential way to share visual information. Therefore, some interviewees favored a combination of telephone and email to solve problems. Results of the current research suggest that these channels complement each other. The main tradeoffs are that telephone calls provide and emphasize the sense of urgency and emails provide visual aids and a written records of communication.

Diminished availability for face-to-face interactions between design and site supervision personnel seem to have strongly influenced this finding.

Finally, even though not specific to design problem solving, several interviewees mentioned being aware of social interactions while choosing a communication channel. Examples of this were interviewees choosing the telephone to convey a sense of urgency, or sending an email when they were uncomfortable transmitting information due to emotional impact on the receiver. This is in agreement with research conducted about Media Richness Theory, as personal focus is one of the criterion for analyzing the richness of a channel (Daft et al., 1987; Sun & Cheng, 2007).

In order to further analyze the impact of media during a problem-solving task, the researcher has developed and applied a quasi-experiment as the third phase of the sequential, mixed-methods approach. The next session describes the results for phase three.

4.3 Phase 3 - Quasi-experiment

Phase 3 was originally designed to have three repetitions for each variable combination (channel and experience). The researcher started inviting volunteers at the end of the month of January 2016, however, data was only collected during the last two weeks of March due to the unavailability of volunteers, especially from students with design background. In order to make the participation more desirable and to increase the number of students volunteers, the researcher:

- decided to accept all volunteers, regardless of their score on the PVST:ROT test. However, participants still had to take the test during the meeting and scores were used to help analyze results;
- increased the amount of reward given to participants from a $10 gift card (when the session lasted around 40 minutes - only pilot), to $20 gift card (when the session lasted around 1h);

- opened to other design-related majors around Purdue such as computer graphics technology, as long as students were familiar with construction plan-reading;
- opened the study to graduate students from design disciplines around Purdue who have had one or fewer years of professional experience.

Other mitigation plans were developed, such as reaching out to other universities in Indiana. However, due to time limits and the approach of the end of the semester, the researcher found it adequate to rely on Purdue university students and acknowledge the limitations of the research. Table 4.17 presents the updated research design for phase 3. This decision was made during the last week of March 2016.

Table 4.17
Final research design for phase three

Variables		Experience Level	
		Students	Professionals
Media Channels	Face-to-face	X	X
	Telephone	X	X
	Email	X	X

Experiments took place in the Wang Hall fourth-floor focus booths (telephone and face-to-face), or the Knoy Hall Computer Lab, located in room 422 (email). The location was changed to ensure that both participants were provided with the same electronic equipment. The information given to participants about the case is presented in Appendix E. The case was developed using the Kokomo Fire Station 2 bid set of plans from July 9, 2010. This use was approved by the Kokomo major's office, and the case developed was not based on actual facts, but rather on the researcher's previous experience and interviews from phase 2.

All participants in phase 3 had available to them during the meeting: a complete set of bid drawings; an engineering scale per participant; blank sheets of paper for notations; and one pencil and one eraser.

4.3.1 Sample Demographics

This phase included the participation of 6 professionals (three designers and three construction managers) and 6 students (three from Interior Design or Computer Graphics Technology and three from the construction management department, all from Purdue University). Invitations to students were sent by faculty of junior and senior courses of Interior Design and junior and senior courses of Computer Graphics Technology with Building Information Modeling emphasis. This was done to ensure that participants were able to read construction plans. Professionals were invited through direct email by the researcher, preference being given to professionals within the Greater Lafayette region since all meetings took place at Purdue University.

A total of three Construction Management Technology students (all undergraduates), two Computer Graphics Technology students (one undergraduate, and one graduate), and one Interior Design student (graduate) volunteered for the task. The professional experience of these students varied from no experience at all to twelve months of full time experience. Three participants were in the 18 to 24 years age range and three others were aged between 25 and 29 years old. All the construction management students who participated in this study were male. Only one design student out of the three who volunteered for this study was male.

Professionals from the construction management discipline who participated in this study all came from the facilites department of a company with 1,000 to 4,999 employees. Professionals from the design discipline worked in companies with varying size: one from a company who had nine or fewer employees, one from a company that had 10 to 49 employees, and one who worked for a company that had from 50 to 249 employees. The professionals who participated in this study had the following background: a civil engineering undergraduate degree (1), construction management undergraduate degrees (2), architecture master's degree (1), and interior design undergraduate degrees (2). Two CM participants and two interior design participants were between 50 and 59 years old. The remaining participants, one from the design discipline and one from the construction management discipline, were between 30 and 39 years old. Professional experience level of participants varied from seven to 36 years of experience, with a mean of 23.66 years and a median of 28.5 years of full-time professional experience.

Finally, all students and professionals who participated in this meeting received an online store gift card in the amount of $20.

4.3.2 Results by group

In this session, results from each group are presented. With this approach, nuances for each combination are explored further. Stempfle and Badke-Schaub (2002) task classification is used to analyze conversation among participants, and scores of the PSVT:ROT are reported in a summarized fashion. Low (L) PSVT:ROT scores represented those with 10 or fewer correct answers, medium (M) scores for participants who obtained between 11 and 20 correct answers, and high (H) scores represent participants who obtained more than 20 correct answers on the test. The solution provided by participants was scored using the rubric presented in appendix D, in which the main specifications include constructability (CS), scheduling & budget (SB), complexity (CX), and aesthetics and usability (AU).

4.3.2.1. Professionals, face-to-face

Participants for this meeting were asked to come to Wang Hall at Purdue University. Because of CM participant's time restrictions, this participant started the PSVT:ROT test before the designer could arrive at the location. The designer took the PSVT:ROT after the construction problem task. Both participants scored high in the test (>20). The designer could only complete 28 of the 30 questions in the test due to the time limit of 20 minutes.

After the CM participant finished the test, the researcher explained to both participants the next task. Both participants were placed in adjacent rooms for a three-minute period to look over plans. During this time, the designer flipped pages quickly until reaching the architectural plans and details. She spent most of her time in this section. The CM participant, on the other hand flipped over the set pages quickly until reaching the structural plans, then moved back to the safety plan and forward again to the architectural plans. After this, he moved back to the beginning of the set where the civil plans are located.

At the three-minute mark, the researcher entered the CM room to explain the issue, as indicated in the protocol in Appendix D. After waiting for the researcher to finish, the CM participant asked if an electrical conduit was considered a pipe in this context, to which the researcher answered that only water pipes were an issue. After this matter was resolved, the researcher continued to explain the constraints with which they would have to work. After explaining both the issue and constraints and waiting to see if the CM participant had any other questions, the researcher asked for the participant to walk over to the Designer's room. When arriving there, the researcher explained to the designer the constraints she had to consider. Both participants were presented with a printed copy of what was discussed. The designer only had a copy of the constraints. Then, the researcher explained the goal of the task and gave them fifteen minutes to complete it.

The CM participant was very concise in explaining the issue and used gestures to point to the data room in the plans while explaining it to the designer: "Okay, so our challenge is this room [CM points at data room] can't have plumbing over it. HVAC is okay." After the designer responds with an "Okay," he continues:

> CM: Electrical is okay… The issue we've got is, of course, it is right were we've got above restrooms currently. So, I mean, this is column line 6 [CM points to plans]. Here is the south edge… so south edge of that room, so basically those two restrooms are sitting right here [points to the data room].

The participant then concludes that they have to come up with a solution to supply the restrooms above without coming from the floor (first floor ceiling). Then he mentions the constraint for the first floor not to change. To which the designer replies: "Oh, 'cause I was thinking that would be an easier solution." After this, both participants analyzed the plans to explore the proposed solution further. After thinking about how to reconfigure the second floor space to solve the issue, the participants started questioning the number of bathrooms available on the second floor. On the second floor there are eight dormitories and three bathrooms. The designer said: "I'm wondering if we could just eliminate one [bathroom]… and make a storage…" After this proposal, both participants search in the set for occupancy specifications, hoping to find more information about the demand for bathrooms in the building.

They cannot find any information in the plans that would help them determine the needs of bathrooms per dormitory, so they decide to explore other options:

> CM: Alright, let's… so if, let's say if that's not acceptable, and we need that restroom, is there another spot that we can swap for?
>
> D: So what if we flip the restroom and then relocate the laundry? Would that be the other solution?
>
> CM: Hm-mm…
>
> D: … because that would be easier to relocate.
>
> CM: Now, the only problem is… Well, I guess…

D: Would it still hang out a little bit?

CM: [CM checks plans dimensions] No, it wouldn't. . . You're right, it wouldn't.

In this solution, participants proposed to swap the restroom for the laundry and then relocate the laundry somewhere else. Worried about not finding another place close by to relocate the laundry, participants then explored other options such as increasing the bathroom size and reducing the laundry. Then they went back to the idea of eliminating one bathroom. However, after counting the number of dormitories and evaluating their size, both participants agreed that they needed the third bathroom on the second floor.

At the 12m06s mark, while discussing relocating spaces on the second floor, the designer proposed swapping the laundry with the bathroom on top of the data room:

D: Okay, so can't we flip that [bathroom 213 with laundry 214]? We can flip that, and make that smaller, or whatever. . . flip the two. . . could we?

CM: Well, you'd have to. . . you'd have to make sure that the restroom. . . well, let's see. . . so. . . yeah, see. . . even if we. . . even if you flipped. . .

D: We still not. . . ?

CM: So we still can't get the casework in. . . [CM gets scale to measure plan] See our [space]. . . right there. So even if we flipped, this whole laundry space would still fall in that area, and you would still got to get. . .

D: Okay. . .

CM:. . . water. . . I guess it's only over. . . wait, wait, wait. . . let me think this through. . . it's just over, so we could bury. . . I mean all this service would be in the wall. . . that would be over, that would be over, that

> would be over...floor drain would be over...So if we did flip, and put...and this wall became that wall, that would work. That would work. 'cause then everything, [flips pages to first floor plan] everything should then run down this wall.
>
> D: Yep.

After this dialog, both participants agree that swapping the laundry with the bathroom 213 is the best option and start to write down the solution on a piece of paper, as requested by the researcher. At the end of the task, the participants discussed their interaction before the researcher entered the room:

> D: ...data room 117. Voila! [CM finishes writing] So you could not have done that as easily if it wasn't face-to-face...
>
> CM: Right. I agree. I agree.
>
> D: But I think it is the easiest way to do it, when you've got something like that...you've got too much...do you imagine how many emails you'd need?

Based on the final solution provided by the participants: 'Rroom 213 trades with room 214. 214 orientation is mirrored. This eliminates plumbing over data room 117." This solution received a score of (2 (x2) [CS] + 2 [SB] + 2 [CX] + 1 [AU] =) 9/10. This solved the issue of relocating all the pipes outside of the data room and did not cause major changes in design or material, since the swapped rooms are side by side. Both participants mentioned not having experienced any misunderstanding and were very pleased in being able to solve this face-to-face. In the post-questionnaire, the designer said that "Face-to-face is the easiest way to solve this problem."

The researcher also analyzed the flow of content according to Stempfle and Badke-Schaub (2002) during the task. Figure 4.8 and table 4.18 present the results, based on coding frequency of words.

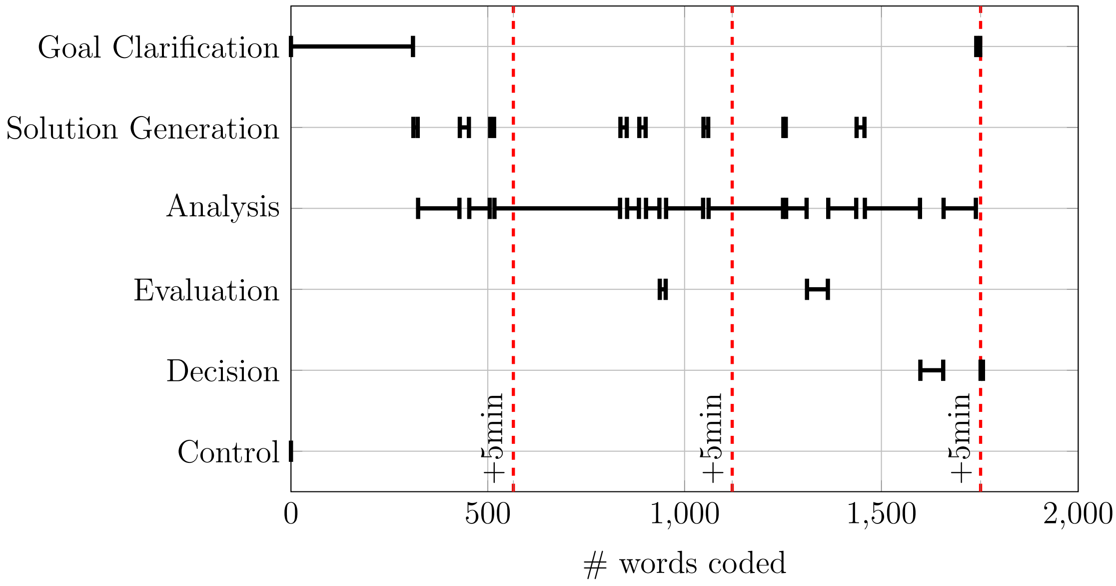


Figure 4.8. Professionals, face-to-face: content exchanged over task progress

Table 4.18
Professionals, face-to-face: content exchanged

Code	Words Coded
Goal Clarification	321
Solution Generation	112
Analysis	1227
Evaluation	79
Decision	66
Control	0

Both participants spent more effort in the analysis of proposed solutions. Another interesting result is the number of solutions generated by the group: (1) rotation of rooms on second floor, (2) eliminate one bathroom on the second floor, (3) eliminate laundry, (4) flip restroom and relocate laundry, (5) increase bathroom size and reduce laundry size, and (6) flip bathroom with laundry. However, when questioned if there was anything she would do differently if given the chance to do the same task again, the designer mentioned: "[I would] give more take [meaning more]: good ideas and not so good ideas." Towards the end of the task, after realizing that flipping the bathroom and laundry would be enough to eliminate pipes inside the data room, participants started the decision process. During the dialogue, there did not seem to be much comparative evaluation of solutions, but rather more analysis to verify if the solution would work against the constraints given. If that solution was not found to be satisfying, participants would try analyzing new ideas. The lack of a comparative evaluation may also be connected to the limited time given for the task, since participants came up with their last solution at the 12m06s mark.

4.3.2.2. Professionals, Telephone

For this meeting, participants met the researcher in Wang Hall at Purdue University, where they were placed in separate rooms to take the PSVT:ROT test. Both professionals in this meeting obtained medium scores for the PSVT:ROT test. These professionals were not able to finish the test completely, providing answers only up to question 26.

After the test, participants were asked to look over the plans individually for three minutes. The designer flipped quickly through the plans in order to get to the architectural drawings. Meanwhile, the CM professional initially flipped pages quickly until reaching the structural plans, when he took more time to observe. The same pattern was repeated when the CM reached the architectural plans and elevations. The CM was still looking over architectural drawings when the researcher entered the room to communicate the issue.

After communicating the issue to the CM participant and letting the designer know the constraints with which they would be working, the researcher gave participants instructions about the goal of the task and started the fifteen-minute countdown. When the countdown started, the CM took one minute and twenty-six seconds to look at the architectural and plumbing plans before calling the designer. When describing the issue, the CM was very precise to let the designer know which pages and rooms he was looking at. This was recognized as a strategy for effective communication by both the designer and the CM during the post-test questionnaire. The following extract shows how the CM presented the issue to the designer.

> CM: I'm working on the project here. . . Looks like we've got some plumbing. . . some plumbing conflicts that we need to work out. . . specifically for [. . .] there is a data center room and we've got some plumbing that is running through it and the site specialist said that this can't happen. So I'm looking at drawings. . . I'm looking at drawings A101 and A102, P201 and P202.
>
> D: Okay.
>
> CM: And what we have is a constraint that I cannot really impact the locker rooms that are on the right hand side, or to the west of the data center room, and the room number for locker room is 107, that's on page A101. Drawing 101.
>
> D: Room 107. Okay. And the. . .
>
> CM: And the data room on drawing A101 is room 117.
>
> D: Okay.
>
> CM: So those are the two primary rooms that, that we are talking about. The plumbing that is affecting the data room, 117, is really for. . . from the restroom on the second floor. From the restrooms and the laundry, so A102, in this drawing, rooms number 202 and 214. So when you look. . . so from there, let's go to P201. . .

The CM was very precise during the goal clarification phase and at each juncture waited for confirmation from his counterpart before continuing, either as an interjection (e.g. 'Hm-mm') or a short confirmation word ('Okay').

After explaining the issue to the designer, the CM suggested a solution: "So, [. . .] the only way I see of doing anything is somehow to get all this piping pushed into the corridor." After this suggestion, the CM explained his idea while referencing room numbers and drawing pages. During the explanation, the designer misunderstood the idea, thinking that rerouting the pipes would take up some of the corridor space (misunderstanding 1): "How much space would it take to run the plumbing out there and to the corridor? 114 and 118. How much? What kind of a chase would you. . . " To which the CM promptly replied:"It would be in the ceiling, first of all." This misunderstanding was recognized by the CM in the post test questionnaire even though the designer did not acknowledge any misunderstandings during the task.

After misunderstanding 1 was resolved, the designer suggested another option for rerouting the pipes: "Do you see any opportunity going the other direction? Into the gear locker room?" This shows that she had forgotten the constraints mentioned in the beginning of the task. The CM then reminded her that they could not go inside the lockers.

They continued the analysis for rerouting the pipes. The designer seemed to be very accepting of the CM's solution even though the CM continues to propose other options, such as those indicated in the following quote:

> CM: Or another way to do this is you build a false ceiling in the data center room that lowers the ceiling just enough that it would make a water-tight ceiling, so you separate the potential leak. . . and you put some access doors. . . I haven't had the chance to look at the drawings to see if it's a drop ceiling or if it's a hard drywall ceiling, but I would. . . the other option is if you can't get into the hallway, just put a false ceiling or

> a drop ceiling and then basically it prevents the water from getting in the data room. Or the third option is to relocate the data room.

The designer refuted the data room relocation, stating that the client probably would not accept this option, but failed to propose any other solutions. It is interesting to note that this group preferred to propose a relocation of the data room, even though the constraints given discouraged such a plan. The group did not explore the relocation of second-floor bathrooms. This could be due to the lack of familiarity the designer had with the task plans.

They continued with analysis of the second proposed option, which was to drop the ceiling over the data room. In communications with the designer, both agreed to provide more than one solution. The solutions presented are ranked, and number one presents the best solution in their opinion:

1. reroute sanitary into corridor 118/114
2. drop ceiling and add a drain pan ceiling
3. relocate data room

Even though the group presented three solutions, the researcher will only base the scores for their on solution number 1, "reroute sanitary into corridor 118/114." This solution received a score of (1 (x2) [CS] + 2 [SB] + 1 [CX] + 1 [AU] =) 6/10. This solution only partially addressed the major issue of relocating all pipes outside of the data room, since participants did not provide a solution for relocating one floor drain and one shower drain from the restroom located above. This is also interesting because the CM specifically talked about the existence of floor drains in the beginning of the task dialogue: "And, what we have here is we have basically those two floor drains, the one that is in the shower, P5, and then the FD-1 that is in 213, are directly over the data center room."

The researcher also analyzed the flow of content during the task according to Stempfle and Badke-Schaub (2002). Figure 4.9 and table 4.19 present the results, based on coding frequency of words.

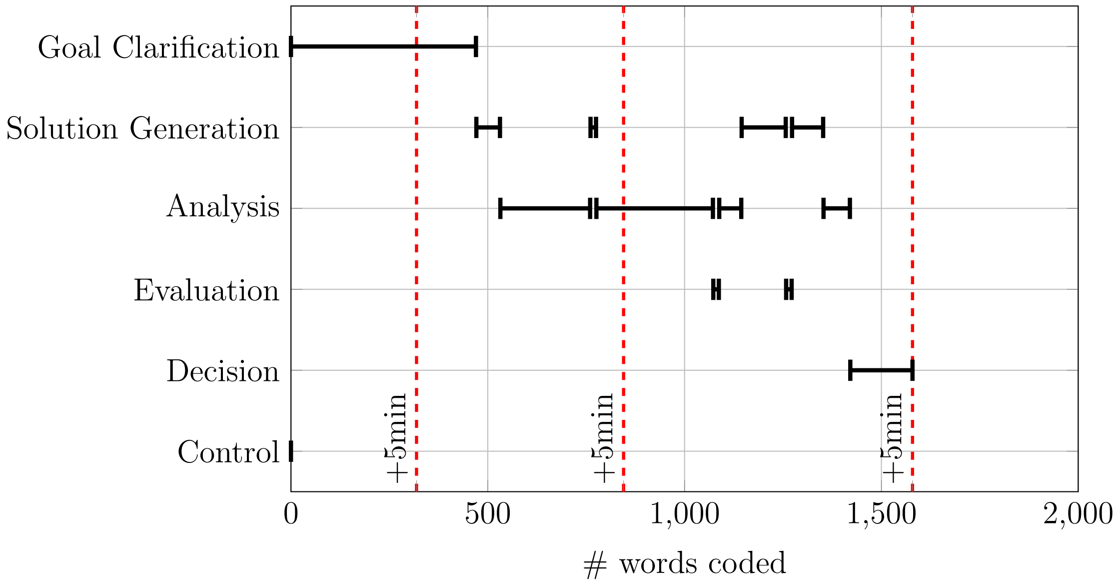


Figure 4.9. Professionals, telephone: content exchanged over task progress

Table 4.19
Professionals, telephone: content exchanged

Code	Words Coded
Goal Clarification	470
Solution Generation	269
Analysis	651
Evaluation	30
Decision	159
Control	0

Readers can see that the greatest allocated time during the dialogue was for analysis, followed by goal clarification. Comparative evaluation of solutions, which would be expected in order to make an informed decision, was reduced. This could be due to time constraints on the task. Finally, during the post-questionnaire, both participants were satisfied with their solution, even though they indicated the task was hard due to lack of familiarity with the project.

4.3.2.3. Professionals, Email

For this meeting, participants were asked to come to Knoy Hall, room 422, which is a computer lab. They were each placed at one end of the lab, diagonally opposite from each other. PVST:ROT scores for these participants were low for the design professional and high for the construction management professional. The design professional only finished 12 of the 30 questions in the test but still seemed calm at the end of the test.

After the test was over, participants were asked to look at the plans for three minutes to familiarize themselves with what the project was. Even though they had digital files and printed copies of the drawing available to them, it was interesting to note that they chose to look only at the printed copies. Both participants seemed calm throughout the session.

At the three minute mark, the CM participant was asked to step out of the room, accompanied by the researcher. Meanwhile, the designer continued to flip through the pages of drawings. When the CM returned to the room, he started immediately to compose an email to the designer. In his email, he described the issue:

> [2 min.] It has come to my attention that the current design indicates that plumbing lines are being routed through the IT room.
>
> In meeting with the IT contractor it was indicated that no water lines are to be routed through this area. We need to get together and figure out how the lines can be rerouted.

In his email, the CM used ‘IT room’ to describe the ‘data room’; this name caused confusion with the designer [misunderstanding 1]. As soon as she received the message, she started to look over both floor plans for the 'IT room,' since no information about floor was mentioned in the message. After reviewing both floor plans for the 'IT room,' the designer replied to the CM at seven minutes into the task: "Remind me again which floor (1st or 2nd) should we look? First floor has tool room and training room?" The CM then replies fast, at eight minutes with more precise information: "1st Floor Rm 117."

After clarifying this information, the designer then looked over plans again in order to search for solutions. Close to the 13-minute mark, the designer offered two solutions to the CM: either route the plumbing lines through the gear lockers or through the corridor. Given this email, the CM replied at the 14-minute mark that the corridor was a better option, since project constraints included no pipes should cross through the gear lockers as well. This indicated that the designer had not taken into account the constraints mentioned in the written document, placed next to her drawings. This could be due to the time constraints of the situation.

As expected, participants exchanged much less communication through email than other groups did through other means. A total of five emails were sent, all of them with only written information, even though electronic files were available to participants in their computer station. Content analysis was performed on those five sent emails. This group's interaction suggests that most of the task analysis was performed individually by participants. Table 4.20 shows how these communication pieces are coded using Stempfle and Badke-Schaub (2002).

Analysis of solutions was performed individually by each member and participants only just arrived at the evaluation phase, when the 15 minutes for the task was over.

The researcher considered the solution as routing pipes through the corridor, based on the last communication sent from CM to designer: "The corridor may be the better solution [...]' This solution received a score of (1 (x2) [CS] + 2 [SB] + 1 [CX] + 1 [AU] =) 6/10. This solution only partially addressed the major issue of relocating all pipes outside of the data room, since participants did not provide a

Table 4.20
Professionals, email: content exchanged

#	Time sent (min.)	From	Words Coded	Code
1	2	CM	57	Goal Clarification
2	7	Designer	21	Goal Clarification
3	8	CM	6	Goal Clarification
4	13	Designer	33	Solution Generation
5	14	CM	17	Evaluation

solution for relocating one floor drain and one shower drain from the restroom located above.

In the post-task questionnaire, participants for this meeting were able to provide more input. Both participants indicated time as the major constraint for the channel used. When asked if there were specific constraints for the channel, the CM mentioned: "Yes, time waiting for a response. Face-to-face is much more effective." And the designer indicated: "Emails sometimes are slower. I prefer telephone or face-to-face. Seems to be [a] faster / quicker solution." It was also interesting that even though the researcher identified a misunderstanding during the task (designer not able to find 'IT room'), when asked, both participants mentioned no misunderstandings during the task.

4.3.2.4. Students, face-to-face

For this session, both participants were asked to meet the researcher in Wang Hall at Purdue University. They were placed each in an individual room, where they took the PSVT:ROT test. The CM participant finished the test in half of the allocated 20 minutes time. The designer took all twenty minutes to finish and did not provide an answer for one question. The designer scored high on the PSVT:ROT, and the CM participant scored medium.

After the test was finished and collected by the researcher, participants were given three minutes to look over plans. During this time, the designer flipped pages at a constant rate of time, taking time to quickly glance through the contents before flipping to the next page. She stopped when she reached the structural plans and then moved at the same constant pace until she reached the architectural plans. She spent more time on the architectural plans and details. The designer seemed not only to look at the drawing but also to read over the drawing notes. The CM had a similar pattern, although his flipping was faster and he did not always glance over the drawings as he flipped pages. He still took more time on the structural drawings, and looked over the architectural first floor plan, until the three-minute mark was reached.

At the three-minute mark, the researcher entered the CM room and explained the issue as presented in Appendix D. As the researcher started to explain, the CM asked if he could take notes, to which the researcher replied that he would have a copy of what was being said. At the end of the problem presentation, when asked if there were any questions, the CM did a brief summary of the problem himself: “Okay, so…just to summarize…the data room is in here, and they have already began to track it out, but they don’t want any wet over it?” To which the researcher indicated that this was correct. The researcher then went to the designer to explain the task and the constraints with which they would have to work. At the end of the description, the designer and CM were left in the same room, and the fifteen minutes were timed.

To explain the task, the CM read the issue from the printed copy the researcher had given him. However, at the end, he made sure to open the set of plumbing drawings and point the data room location to the designer. Then he explained where the pipes were coming from and proposed a solution:

> CM: [flips drawing pages from first-floor to second-floor] Here is the second-floor. Sorry, sorry, all of this is running from the second-floor, so second-floor, this is going to make much more sense. . . We need to take all of this and flip it [making a flipping movement with fingers].
>
> D: Right here?
>
> CM: Yeah, flip it. So we've got one, two, three, four dorms, and there is here basically all the water stuff, flip it into the dorms.

The designer did not understand the CM's proposal to flip rooms and pipes (misunderstanding 1) and questioned him:

> D: I think that having the sewer line here in the room could make some noise, I guess. . . at night especially.
>
> CM: I'm saying. . . No, I'm saying take all these rooms here. . .
>
> D: All of the rooms here, not only the pipes, then?
>
> CM: Right, no no no no. So all of these would then move to these rooms [points to plans] And then all of those rooms would become these rooms.

She then understood the implications of this proposal, such as preventing these spaces from having an outside-facing window:

> D: In my opinion, having [a] window is important for users, I guess, so. . .
>
> CM: Okay.
>
> D: So having [a] window is important to allow the daylight in during the daytime and that can improve the quality of life, so having [a] window is important.
>
> CM: So what if we put skylights?
>
> D: Skylights in here? [designer points to plans]

CM: Because if these were the rooms now. What if we put four skylights on?

D: Four skylights can... I think having skylight cannot [let in] the wind, or fresh air...

CM: Oh, that's fine.

The CM seemed to realize that this option was not ideal by the end of the previous dialogue, however he indicated he has misunderstood his design peer when she talked about windows. Even though the participant felt he had misunderstood his peer, the researcher could not identify the dialogue corresponding to this misunderstanding. This could be something that the participant felt as the designer spoke but then was resolved without any intervention, or it could indicate that the CM student did not understand the issues with dormitories not having windows by the end of the task and did not communicate this misunderstanding.

After having been warned by the designer that windows are important features for dormitories, the CM proposed a new solution to shift some second floor rooms. Their next suggestion was to merge some bedrooms in order to provide space between dormitories 4 and 5 for the restrooms 212 and 213. Then they explored moving all restrooms to the workout area and creating a corridor to access them:

D: So move the restrooms here [points to plan] and get some corridor to come into the restroom.

CM: Yeah.

D: Hm-mm. And laundry area?

CM: Maybe that whole...

D: Can we... can you leave this restroom here?

CM: Hm... [flips pages in drawings]

D: Just one?

CM: Hum…

D: Is it possible?

CM: No. It doesn't look like it because there is no waste line up here. 'Cause you're bringing the waste through the wall here [points to plans].

The designer was worried about moving all the second floor restrooms to one corner of the building. However, at that moment she did not explicitly indicate the reasons for this to the CM, who analyzed the issue in terms of practicality. However, when exploring this solution further, she mentioned that "Because moving all these restrooms to here can be bad because of the circulation can be way over than the previous one." Listening to this, the CM proposed the solution of reducing the dormitories again. The designer then continued to analyze the shifting of the workout room. They continued their analysis while the CM was paying special attention to the flow of sewer waste lines in order to minimize the use of material. The CM said: "Yeah, because the materials is already ordered, so I don't… if we have enough to stretch over this way. This is going to be a shorter distance, if not equal to that would have already been."

After studying the positions of the rooms on the second floor, the two participants agreed to the final solution (although they did not compare solutions for a broader evaluation): "Move three restrooms (215, 213, and 212) to work-out room (218). Move laundry to storage room (202). Turn room 212 [into] the new storage room (202). Turn 213, 215, 214 into the work-out room (218)." However, this group reached this solution at the 15m mark, and took an extra 1m53s to write it down.

The solution proposed by this group was scored by the researcher as (2 (x2) [CS] + 1 [SB] + 0 [CX] + 1 [AU] =) 6/10. This solution addressed all major issues of relocating all pipes outside of the data room, however it was very complex, as it would change a great part of the second floor layout, including perhaps the change of windows in the current workout room (218).

The researcher also analyzed the flow of content during the task according to Stempfle and Badke-Schaub (2002). Figure 4.10 and table 4.21 present the results, based on coding frequency of words.

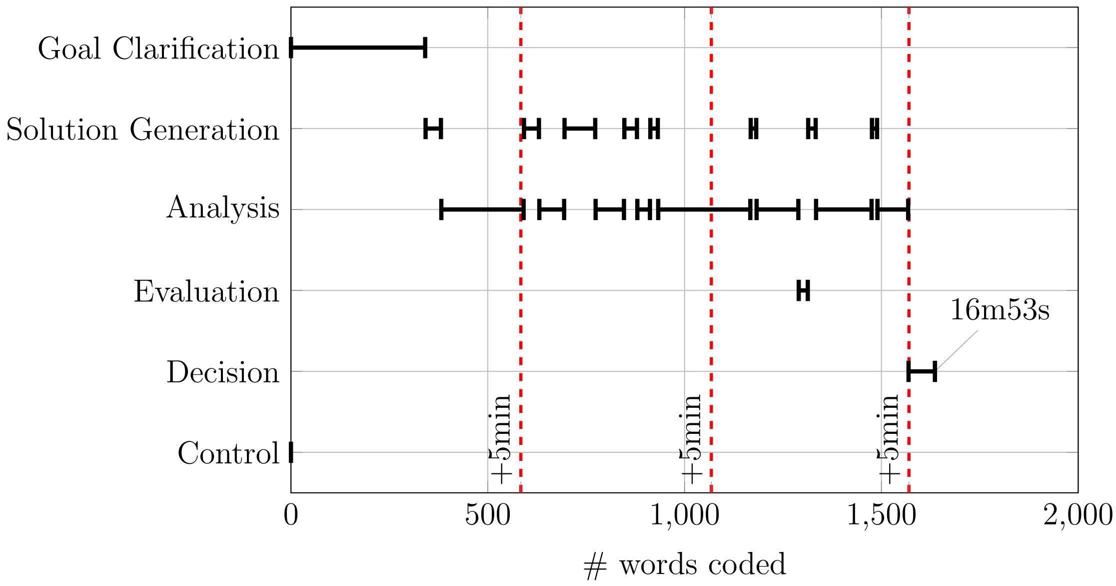


Figure 4.10. Students, face-to-face: content exchanged over task progress

Table 4.21
Students, face-to-face: content exchanged

Code	Words Coded
Goal Clarification	380
Solution Generation	221
Analysis	943
Evaluation	24
Decision	68
Control	0

This group's pattern of content flow was similar to that of the experts' face-to-face communication. Participants however had a briefer goal clarification phase and started brainstorming ideas more quickly. The CM was the major contributor for idea generation. The designer, even though not generating the greater part of the proposals, analyzed ideas that were mentioned conjointly with the CM. The analysis of proposed ideas was again the most frequent type of content in this task. This group did perform a brief evaluation but did not compare all solutions mentioned at the end of the task. Again, the decision for the use of the final solution could have been influenced by the allocated duration of the task (15 minutes).

In their post-task questionnaire, the CM indicated that his peer "brought great insight into design aspects." The feeling seems to be mutual, as the designer mentions that"It was great to have interaction with one who has other opinions. We could make [a] better solution by giving different advice."

4.3.2.5. Students, Telephone

Again, Wang Hall at Purdue University was used as the setting for this meeting. Participants were placed in separate rooms and took the PSVT:ROT test prior to the main task. Both students in this meeting obtained high scores for the PSVT:ROT test and completed all of the questions.

After the PSVT:ROT test, participants were asked to look over the plans individually for three minutes. The designer flipped quickly through the plans until reaching the structural plans, then she went back to the cover page and looked for the page numbers for the architectural drawings. She then opened the architecture plans and looked at them with apparent care. The CM, on the other hand, flipped pages quickly but consistently, just opening the set enough to glance at each drawing. He moved in a steady pace until reaching the architectural plans, where he spent more time before flipping to other pages again. As the three-minute mark was reached, the researcher went inside the CM's room to explain the issue. As soon as the researcher finished speaking, the CM asked about the data room and the pipes in it:

> CM: Okay, so which room is the electrical room. . . that's the data room? [CM points to plans]
>
> R: Yes.
>
> CM: Okay, so where is it supposed to be coming from? Or going to? Is there an equipment room or mechanical room?
>
> R: Well, the equipment or the pipes?
>
> CM: I mean where are these pipes coming to or from?
>
> R: Well, that's a problem that youll have to look at.
>
> CM: Oh, okay [laughs]

After finishing explaining the issue and making the designer and CM aware of the goals for the task, the researcher started the fifteen-minute timer. However, the CM did not call the designer immediately. Instead, he took 1m29s before calling the designer. During this time, he went over the plumbing plans for the area. When calling the designer and before he could explain what the issue was, the designer stated the constraints given to her. The CM waited for the designer, then delved back into explaining the issue.

> CM: Okay. Alright. . . Well, the issue is in the data room, first floor, to the right of the locker room. . . all those pipes in there, we can't have them running through the ceiling. That was an issue with the data contractor when they came out to do a site visit. So, the issue there is that all those pipes are drains and supply lines.

To which the designer responds: "Hold on. Which room are you talking about?" which clearly indicates a misunderstanding (misunderstanding 1). The designer indicated this as a misunderstanding, although the CM student did not.

However, during their post-test questionnaire, both indicated that not having being able to point to specific places on the drawing added constraints to the channel. The CM explained this in the questionnaire: "The telephone had constraints. My peer couldn't see what I was looking at, and I couldn't point it out so I had to explain." Even though positioning the data room did not happen without misunderstanding, the issue was solved quickly, through the following dialogue:

CM: Hum. . . the data room?

D: What's the room number?

CM: [One hundred and] seventeen. . . hum. . . if you go to page 2. . . P201. It's towards the back.

11. D: Okay, P201. Data room? [talks to herself] Okay, I see that.

Having sorted out this communication issue, the CM mentioned that the pipes above the data room were from drains and supply lines from the upstairs bathrooms. He proposed two solutions: to reroute pipes or to move the upstairs bathrooms to different locations. The CM continued to explore only the second option provided - to move the upstairs bathrooms. He proposed swapping those bathrooms with two dormitories (dormitories five and six). However, after a few seconds he proposed using dormitories three and four instead of five and six: "Or we can even do it three and four and then just group all the restrooms closer together, close to that end of the hallway." The CM also mentioned after this that all the material had already been ordered, but he said that this would not be an issue, clearly indicating a construction-management approach to the issue. The designer was overall very accepting of this solution, even though the spaces did not match the dimensions and the dormitories, if moved to the bathroom area, would not have an outside facing window. This could be a limitation of the background of this student, whose experience is in modeling and not necessarily in design for the end user.

Having proposed two solutions and analyzed one with no objections or new proposals coming from the designer, both participants agreed to the solution of swapping bathrooms 212 and 213 with dormitories 3 and 4.

> CM: Hum. . . yeah. I guess I'm good with that plan if you are.
>
> D: Yeah, so we are going to switch the bathrooms to dorm three and four, and have the restrooms all close to one location. And hum. . . yeah.
>
> CM: Yeah. . . we'll just swap them to the three and four. And then put dorm three and dorm four where restroom 213 and restroom 212 are. Alright. Does it sound good?
>
> D: Okay. Sounds good.

After this dialogue, they disconnected the call at the 5m43s mark. They then asked the researcher about which of them had to write down the solution. The researcher said that they needed to decide that by themselves and they needed to call each other to define this. The CM then called the designer back and said that he would write up the solution. The designer hung up this call at the 8m17s mark. After that, the CM spent until 13m30s to finish writing the solution. During this time, he looked constantly to the plumbing drawings. Their full solution was:

> We will relocate restrooms 212 and 213 on the second floor to the location of dorm 4 and dorm 3. Drain lines will be relocated to flow across the ceiling at the first floor hallway and tie into the drains for restroom 215 on the second floor. Additional pipe may need to be procured for the extension across the hallway.

Based on this solution presented by the group, the score was calculated to be (1 (x2) [CS] + 1 [SB] + 0 [CX] + 0 [AU] =) 3/10. This solution addressed the major issue of relocating all pipes outside of the data room, but it created a new issue because dimensions of the swapped rooms were not the same. Because of the new issue created, this solution would probably take longer to resolve, and it would negatively impact the building; if left as proposed, dormitories would not be able to have outside windows, limiting fresh air inside those spaces.

The researcher also analyzed the flow of content during the task according to Stempfle and Badke-Schaub (2002). Figure 4.11 and table 4.22 presents the results, based on coding frequency of words.

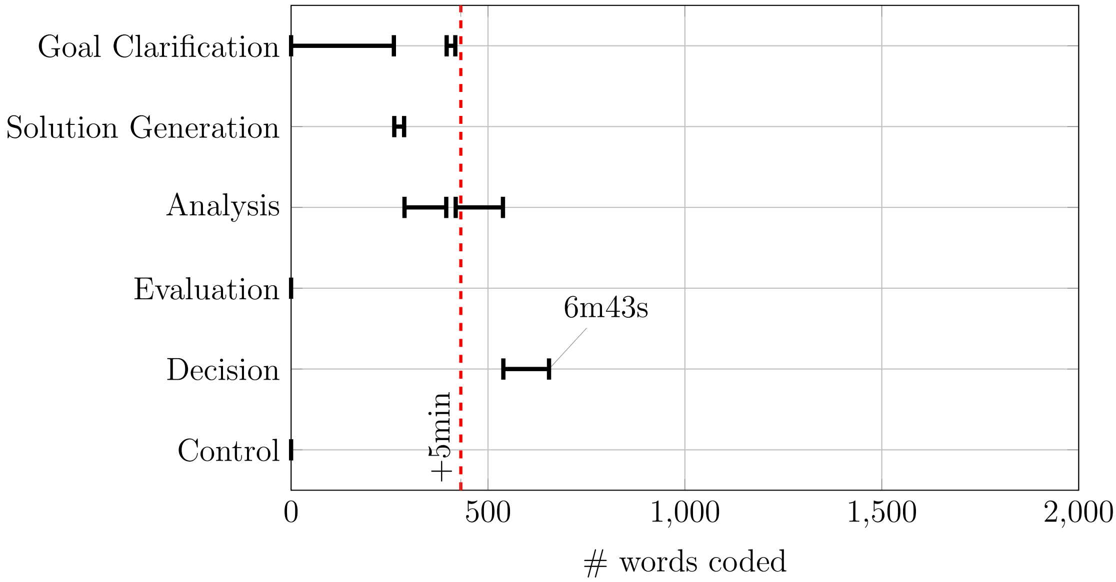


Figure 4.11. Students, telephone: content exchanged over task progress

This group was the only one that had a greater time allocated to goal clarification than to analysis. This may be due to a lack of solution alternatives generated during the task. With only one solution explored in depth, participants also did not perform any evaluation, heading straight for the decision of maintaining the solution to swap bedrooms for restrooms. During the post-questionnaire, both participants indicated that they were satisfied with their solution and both also felt that the problem was easy. This could indicate that both participants were not fully aware of the impacts generated by their solution.

Table 4.22
Students, telephone: content exchanged

Code	Words Coded
Goal Clarification	284
Solution Generation	26
Analysis	228
Evaluation	0
Decision	117
Control	0

4.3.2.6. Students, Email

Student participants for the email meeting were asked to come to Knoy Hall, room 422 (computer lab), at Purdue University. They were placed in the same position as the professionals were. PVST:ROT scores for both these participants was high. Both participants finished the test before the 20 minutes ended.

As in the previous email interaction, participants were given three minutes to look over the bid set containing the plans. Again, and similar to the professionals, even though they had digital files and printed copies of the drawings available to them, both participants chose to look at printed drawings.

At the three-minute mark, the CM participant was asked to step out of the room, accompanied by the researcher. Meanwhile, the designer continued to flip through the pages of drawings and also makes sketches on a blank piece of paper using the scale provided. When the CM returned to the room, he seemed a bit confused about what was asked of him and if the fifteen minutes included coming up with the solution, and writing the solution, or only communicating with his peer. The researcher explained that it should include both, and that all communication between them should be done via email. That being said, he immediately started to compose an email:

> [3 min.] Hope all is well. We are currently facing an issue on the jobsite. The Data equipment company has brought to my attention a few things:
>
> We cannot have any pipes passing over the data room (HVAC Ducts are okay). It is to be noted that plumbing installation will start in 2 weeks and all the material has been ordered already. Also, the current plumbing engineer has said he is willing to change the drawings, but I would like to propose a solution with your help first.
>
> The Data Room can be seen on Page A101, about in the center of the drawing, and it is numbered by the callout (117).
>
> Please do not hesitate to fire my way any proposed solutions!

Interestingly, the student is much more precise in giving directions to the room than the professional CM. The student used the name given to the room in the plan, and also indicated the floor the room and room numbers according to the set of plans.

Meanwhile, the designer asked the researcher about which email to use. In response, the researcher showed him the screen with a logged-in a Gmail account and told the participant that the email would arrive there.

Even though the email seemed clear, upon receiving and reviewing plans, the designer sent an email back to the contractor at the seven-minute mark asking for clarifications: “So basically, no pipes going in and out of the data room?” To which the contractor immediately responded: “Yes.”

After this clarification, the designer went back to looking at plans (and so did the contractor). At the thirteen-minute mark, the designer then proposed a solution: “One solution I have is to relocate the pipes in the data room to the gear locker room next to the data room so the pipes would go through the gear locker into storage instead.” Again, the student designer did not pay attention to the printed version of the constraints, even though it was pointed to him. This solution was rebutted by the CM in the following email, at the fourteen-minute mark:

> [14 min.] Your solution may be possible. Due to regulations we cannot change any layout on the first floor for any plumbing or piping. What I am proposing now for floor two is to reroute all piping systems through the corridor of level 1/2 based on owner approval. With this solution many issues may arise, such as slope.
>
> With this being said, I think it will be best to reroute all piping not conflicting with the Data room and run it through the corridors.

Interestingly, the CM participant mentioned that pipe layouts for the first floor could not change, even though the constraints included 'floor layouts.' According to his designer peer, this caused a misunderstanding (misunderstanding 1): "When [CM] told me we could not change the first floor layout, I did not know it means not changing the plumbing on the first floor." He also did not recognize that the designer's proposal included having pipes through the gear lockers, which also was unauthorized per the constraints. After reading this message, the designer started an email to respond. However, the fifteen-minute mark sounded and the researcher asked participants to stop with what they were doing at that moment.

Again, as expected, participants exchanged much less communication than other students groups using other means of communication. A total of five emails were sent, all of them with only written information, even though electronic files were available to participants in their computer station. Again, content analysis was performed only on the email, and observation suggests that most analysis was performed individually by each participant. Table 4.23 shows how these communication pieces are coded using Stempfle and Badke-Schaub (2002).

Analysis of solutions was performed individually by each member. And participants had not formally arrived at the evaluation phase when the 15 minutes for the task was over.

Table 4.23
Students, email: content exchanged

#	Time sent (min.)	From	Words Coded	Code
1	2	CM	124	Goal Clarification
2	7	Designer	15	Goal Clarification
3	8	CM	1	Goal Clarification
4	13	Designer	35	Solution Generation
5	14	CM	85	Solution Generation

The researcher considered the solution as the one presented in the last email sent by the CM: rerouting pipes through the corridor in floors 1 and 2. This solution received a score of (1 (x2) [CS] + 1 [SB] + 1 [CX] + 1 [AU] =) 5/10. This solution only partially addressed the major issue of relocating all pipes outside of the data room. Participants did not resolve how one floor drain and one shower drain from the restroom located in the restroom above the data center would be relocated. Also, the students' solution to reroute piping for levels one and two would require a major revision in plumbing drawings, which would probably negatively affect the construction schedule.

In the post-task questionnaire, participants for this meeting were able to provide more input. The CM participant indicated time constraints as the main disadvantage of using email. The designer indicated that writing an effective email was difficult and that "sometimes the message can be misunderstood." The CM participant also recognized that he misunderstood the original problem by believing he could not change the pipe layout on the first floor (as opposed to floor layouts as the original issue was presented). This might be due to his academic focus on mechanical construction as well as participating in student organizations that focus on mechanical construction.

4.3.3 Summary of results

All meetings for phase three were performed during the month of March 2016, within the West Lafayette Campus of Purdue University. Table 4.24 presents the summary of results from the quasi-experiments developed in phase 3, including the number of communication turns, number of identified misunderstandings, amount of time to solve identified misunderstandings, solution score, PSVT:ROT scores, and gender of participants.

Table 4.24
Summary of results for phase 3

	Professionals			Students		
	FtF	Phone	Email	FtF	Phone	Email
# communication turns	147	84	5	140[a]	49[b]	5
number of mis.	0	1	1	1	1	1
time to solve mis. (min.)	-	<1	5	1	<1	1
solution score	9	6	6	6	3	5
PSVT:ROT designer	H	M	L	H	H	H
PSVT:ROT CM	H	M	H	M	H	H
Gender designer	F	F	F	F	F	M
Gender CM	M	M	M	M	M	M

Note. PSVT:ROT scores: L=low, M=medium, H=high
Gender: F=female, M=male
[a] for 16m53s of task
[b] for 13m30s of task

A communication turn is defined as the complete series of phrases a participant communicates to their peer before communication moves to the other member of the group. For example, in the following dialogue (extracted from the professionals' face-to-face meeting) has six communication turns:

[Turn #1] CM: So I don't know...

[Turn #2] D: But the second floor can change?

[Turn #3] CM: Yes... The only problem I got with that is that I have already my material on order

[Turn #4] D: Okay.

[Turn #5] CM: And it's going to show here in a couple of weeks.

[Turn #6] D: Okay.

Misunderstandings were identified by the researcher based on the analysis of transcript and video recordings. Scores were also determined by the researcher, based on the rubric provided in Appendix E. This rubric was reviewed by a faculty member from the School of Construction Management Technology who has more than ten years of industry experience. Finally, scores of the PSVT:ROT are reported in a summarized fashion, with low (L) scores representing those with 0 - 10 correct answers, medium (M) for those scoring from 11-20 correct answers, and high (H) for those scoring more than 20 correct answers on the test.

Results obtained show a significant difference in number of communication turns by channel. Users of face-to-face communication, which is the control variable, used more communication turns during the task, indicating more dynamic participation. Email was the channel in which users provided the least communication turns, with only five turns for both students and professionals. Results suggested no significant difference between professionals and students in terms of communication turns.

The number of misunderstandings was also low across all groups. Professionals in a face-to-face environment experienced no misunderstandings during the task, while all other combinations of variables had one. Telephone misunderstandings were resolved in less than one minute for both students and professionals. Students also had misunderstandings during face-to-face and email conversations, which were resolved in one minute. Time used to solve misunderstandings was rounded to the nearest minute.

Scores of solutions also varied, though professionals were overall equal to or higher than students. Professionals in a face-to-face situation provided the solution with the highest score (9), while students using telephone communication provided the solution with the lowest score (3). Students and professionals using email provided similar solutions, however students suggested changing the second floor plumbing and therefore obtained a lower score. Both groups provided very limited solutions using email, and this might be due to the low number of communication turns exchanged between participants. Table 4.25 presents the summary of proposed solutions per group.

It is interesting to note that three of the six groups decided to propose rerouting pipes through the corridor. However only professionals in a telephone communication explicitly acknowledged the existence of a floor and a shower drain above the data room. The other two groups who proposed to reroute pipes through the corridor were communicating through email. During email communication the solution analysis process was slower, with only five communication turns between participants. Therefore, solutions generated did not seem to be thoroughly (or even minimally) analyzed by both participants during the time of the task.

The other three groups chose to change the second-floor layout. However, while students reconfigured several rooms, professionals only changed the minimum necessary to reroute the pipes over the data room.

Table 4.25
Proposed solutions per group

Experience	Channel	Proposed Solution
Professionals	Face-to-face	Room 213 trades with room 214. 214 orientation is mirrored.
	Telephone	1. Reroute sanitary into corridor 118/114; 2. Drop ceiling and add a drain pan ceiling; 3. Relocate data room.
	Email	The corridor may be the better solution.
Students	Face-to-face	Move three restrooms (215, 213, and 212) to work out room (218). Move laundry to storage room (202). Turn room 212 [into] the new storage room (202). Turn 213, 215, 214 to the workout room (218).
	Telephone	We will relocate restrooms 212 and 213 on the second floor to the location of dorm 4 and dorm 3. Drain lines will be relocated to flow across the ceiling at the first floor hallway and tie into the drains for restroom 215 on the second floor.
	Email	What I am proposing now for floor two is to reroute all piping systems through the corridor of level 1/2 based on owner approval.

Table 4.26 presents a summary of the coded discussion content per group during the task. It is possible to see that three groups spent the majority of the time discussing content related to the analysis of generated solutions. Groups communicating through email did not exchange emails regarding the analysis of

solutions but either focused in goal clarification, solution generation, or, the case of professionals, evaluation of previously generated solutions. This does not indicate that analysis was not made, just that it was not exchanged explicitly between participants.

Table 4.26
Summary of words coded per discussion content-type for phase 3 groups

	Professionals			Students		
	FtF	Phone	Email	FtF[a]	Phone[b]	Email
Goal Clarification	321	470	84	380	284	140
Solution Generation	122	269	33	221	26	120
Analysis	1,179	651	0	943	228	0
Evaluation	70	30	17	24	0	0
Decision	66	159	0	68	117	0
Control	0	0	0	0	0	0
Total	1,758	1,579	124	1,636	655	260

[a] for 16m53s of task duration

[b] for 13m30s of task duration

The only other group who had more content in a code other than analysis was the student group using telephone communication. This group had more words coded in the goal clarification phase, followed by analysis and solution generation. The low number of words exchanged related to analysis between the students using the telephone may help explain their low score for the results.

None of the groups achieved the control phase, which was expected since this was indicated as "control of the implementation of a solution idea" (Stempfle & Badke-Schaub, 2002, p.448). This code would be used only after the implementation of a solution, which was not contemplated during this activity.

Finally, through the analysis of group interaction, the researcher was able to identify some strategies used by participants to deal with each channel's specificity:

- Face-to-face: both students and professionals used gestures and pointing to plans as part of their communication strategy during the task. Participants indicated no constraints in the use of this type of communication;
- Telephone: Professionals (especially the CM professional) used very specific spatial descriptions to help peers locate spaces in the plans. This strategy was not used by students until a misunderstanding in the beginning of the task required a more specific language by the CM participant. Professionals did not indicate difficulty in dealing with telephone. On the other hand, both students indicated that not being able to point things out in the drawing (as one would do during a face-to-face meeting) was a constraint of this channel;
- Email: Both participants faced delays in communication due to language. The professional CM did not use the same room-name as presented in plans; the CM student, on the other hand was precise about the location of the data room, but was vague with the designer when describing the issue and therefore the designer replied requesting confirmation. A constraint-specific to this channel mentioned by three of the four participants was the time it took to get information back from their peer.

Results suggest that perceptions of channel constraints are not dependent on the experience level of users. Strategies used by both students and professionals did not vary for face-to-face communication. However, during telephone communication, professionals (CM) were more precise than students when describing spatial information. This was the opposite of what was observed in email, where students (CM) were more precise when describing room information on drawings. Although these results are interesting, they are limited to findings of only one group per variable combination and must be analyzed as such. Further limitations of this research will be described in Chapter 5 of this dissertation.

4.3.4 Discussion

Results obtained were compared to previous studies, in order to understand similarities and differences. As expected, professionals provided higher scored solutions than did students. Professionals' solutions included smaller changes to layout, such as inverting the laundry with the bathroom or re-routing pipes into the corridor, even though the effectiveness of those changes might be questionable. Students using email also proposed re-route pipes into the corridor, however they also indicated that not only first-floor pipes but also second-floor pipes should be re-routed. Professionals making smaller changes may indicate their underlying understanding of the consequences those changes may cause in an ongoing construction site, which is consistent with issues discussed by Thomson et al. (2006) for constructability and time management of changes during the construction stage. This reflects the tacit knowledge of professionals, acquired during their professional years of experience (Dave & Koskela, 2009; Gacasan et al., 2016; Nesan, 2012). This is also consistent with Bryson et al. (1991), who mentioned that expertise level influences how participants understand which variables and constraints are important. However, professional groups in this study did not solve the problem in less time as expected of teams with more experience (Pollock, 2000). This could also be influenced by the short amount of time available to participants to solve the problem, although students in the telephone situation did solve it in less than the stipulated 15 minutes.

Both student groups in a face-to-face and in a telephone situation provided solutions that solved all the issues related to pipes over the data base. However, they did not account for other usability issues or time management to implement those changes during the solution process. This is consistent with their lack of experience in industry (Thomson et al., 2006) and lack of expertise in evaluating important constraints (Bryson et al., 1991). This lack of awareness could be the reason that both student participants in a telephone situation were satisfied with their solution and indicated the issue presented as 'easy'.

Results also suggest that the amount of information exchanged changed mainly by channel used. No significant differences in the amount of information exchanged were found to exist between professionals and students. The control factor, face-to-face communication, resulted in more interaction between peers (143 to 147 communication turns, with 1,744 to 1,938 words exchanged), as opposed to email, which resulted in the least amount of information exchanged (5 communication turns, with 124 to 251 words exchanged between peers). The number of miscommunication issues was equal to one in all factors' combinations, except for expert face-to-face, which had no issues. This might reflect similar findings to Liu (2009), in which misunderstanding was considered fifth place for communication issues during construction stage. In his study, Liu (2009) found that information underload was the top issue for communication problems, and inaccuracy was ranked third place. This finding might explain students' results over phone communication. In this situation, the students finished the task early, with only 49 communication turns, and with very little input from the designer. Their solution scored the lowest, mainly due to creating adverse living conditions for users despite solving the issue of the pipes over the data room. Limitations to this interpretation may apply, since it is unknown whether participants would yield a different solution if increased the number of communication turns.

Time to solve the misunderstanding issues varied; however, miscommunication issues were solved more quickly over the phone than through email. Students in a face-to-face situation had a misunderstanding in face-to-face communication regarding the positions of pipes below the bedrooms, which took one minute to resolve. The higher amount of time was due to the time it took for the participant who misunderstood the concept to realize the misunderstanding (that not only pipes would be flipped but all bedroom locations would be flipped as well and therefore there would be no pipes under the bedrooms).

Participants' perceptions of the channels used, collected by their responses in the post-test questionnaire and through video-footage analysis of the task, correspond with findings from Media Richness Theory (MRT) and media synchronicity. Participants who used email communication were frustrated by the amount of time it took to receive answers, a problem also identified by Fox et al. (2010) in their study on use of communication media within the AECO industry. This happens because, in an asynchronous communication such as email, feedback is not immediately available to participants. Results suggest that the immediacy of feedback seems to be more important to participants than the lack of visual cues or verbal intonation, which are limiting factors described in MRT (Daft et al., 1987; Straus, 1997; Sun & Cheng, 2007). Participants in a face-to-face situation, on the other hand, were pleased with their interaction. They used visual cues extensively during the task, such as hand movements and pointing to plans. This perceived effectiveness of face-to-face communication, based on visual cues and verbal communication is characteristic of the richest communication channels as explained by Daft et al. (1987).

In contrast to other channels, where professionals' and students' opinions about channel constraints converged, telephone communication was perceived differently by students and professionals. In this situation, the CM professional indicated an awareness of the channel's limitations, using more precise language to overcome those issues. Students in a telephone situation, on the other hand, indicated that not being able to point to drawings was a limiting factor of the channel. The absence of visual cues is characteristic of telephone communication according to Daft et al. (1987); both professionals and students faced this constraint even though they dealt with it that limitation differed.

Results obtained here were also consistent with Stempfle and Badke-Schaub (2002) regarding experts' face-to-face and telephone interactions and students' face-to-face interaction. In these three situations, participants spent more time analyzing solutions generated than they did discussing goal clarification, solution generation, evaluating, deciding, or controlling for solutions applied. Email communication has the limiting factor that very few interactions were exchanged, and most analysis seems to have been performed by each participant individually and therefore was not captured in emails. Students in a telephone setting were the only group with synchronous communication that had more words coded for goal clarification than analysis.

Groups in this study also showed no discussion related to the control of the solution implemented, which is consistent with Stempfle and Badke-Schaub (2002), who also performed a quasi-experiment about design problem-solving. Similarly to Stempfle and Badke-Schaub (2002), the goal clarification phase for this study took place in all groups during the beginning of the task, but only students in a telephone situation returned to goal clarification towards the second half of the task. However, this does not seem to have improved solution generation, since as participants in this group only generated one solution throughout the task.

Contributions to solution generation varied by group and could have been influenced by factors outside the scope of this research, such as introvert personalities. Results indicate that teams in a face-to-face situation had a higher amount of peer interaction between team members, represented here by communication turns and words, in addition to being able to use other visual cues, such as gestures. These teams not only had higher interaction, but both team members contributed to solution generation, as opposed to telephone interactions in which only the CM proposed solutions, which were then analyzed by both participants. If one analyzes students' and professionals' group separately, groups with higher amount of peer interaction were more successful in obtaining a higher score. This is consistent with research on problem solving by Sonnenwald (1995), Chiu (2002), and Stempfle and Badke-Schaub (2002), which indicates that effective communication between participants is essential for the development of design outcomes. This may also explain the issues with the problem-solving process using email communication, in which interaction between participants was much lower than in the other two communication channels.

In summary, results obtained are consistent with findings about Media Richness Theory and media synchronicity: face-to-face communication enables for a richer and more immediate exchange of information between peers (Daft et al., 1987; Straus, 1997; Sun & Cheng, 2007); groups who have active solution generation and communication interaction from both peers are more successful in their solution proposal (Chiu, 2002; Sonnenwald, 1995); and professionals with an implicit knowledge of evaluation of important constraints by provided solutions with fewer constructability, usability, and time management impacts (Bryson et al., 1991; Thomson et al., 2006).

4.4 Summary

In this chapter, the researcher presented major results for all three phases of this study: phase 1 - online survey of professionals regarding most helpful channels for design problem-solving in time-restricted situation; phase 2 - interviews with professionals regarding design and regular problem-solving strategies in their professional environments and how different channels impact their communication in these situations; and phase 3 - quasi-experiments of pairs of students and pairs of professionals in a design problem-solving situation using different means of communication (face-to-face, telephone, and email).

At the end of each of the aforementioned phases, a brief discussion of results is presented in order to verify findings against what was indicated in the literature review (chapter 2). In the following chapter, the researcher will present an overall discussion of findings, conclusions, limitations, and future study recommendations regarding communication in construction, as studied in this dissertation.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes previous literature and results from this dissertation. A brief discussion will be presented regarding how the combined results from all three phases compare to previous literature. Then, the author will present conclusions specific to how the choice of media affects problem solving between design and site supervision personnel in construction, including guidelines to help students and young professionals deal with constraints and take advantage of the media they use to solve design problems containing spatial information. These guidelines will be reviewed and commented on by two faculty with previous industry experience in order to provide some face validity to the proposal.

Finally, limitations found during the course of the research will be enumerated. Readers should take these limitations into consideration when analyzing the findings and conclusions of the present research. At the end, recommendations for future studies that may add to the knowledge created and discussed in this document will be presented. The author hopes that this dissertation will positively contribute to understanding about communication within the AEC industry.

5.1 Overall Discussion of Results

This research proposed to study how the choice of media influences communication in construction. A three-phased sequential approach was used and results were presented in Chapter 4 (Results). Findings from each phase were compared to previous literature before advancing to the next phase. In this section, the researcher will present how the overall findings relate to each other and to previous published work.

5.1.1 Availability to face-to-face interactions

In all phases, face-to-face was indicated as the most preferred form of communication. Results from statistical tests and descriptive analysis indicated face-to-face as the most helpful channel for solving design problems with spatial information. This is consistent with Media Richness Theory (MRT), which takes into account three main reasons users select certain media: content, symbolic cues, and situational factors (Trevino et al., 1987). In all phases of this dissertation, respondents indicated that their first choice of communication was face-to-face. This was also found by Gorse et al. (1999) when researching construction communications at the end of the 1990's.

However, many survey respondents in phase 1 and interviewees in phase 2 indicated that situational reasons often did not allow for face-to-face communication. The main reason mentioned was availability of design professionals to be present at the job site. Situational reasons were found by Trevino et al. (1987) to influence the selection of other types of communication which were not face-to-face.

Also, due to tacit knowledge held by professionals in the AECO industry, Nesan (2012) indicates that the preference for face-to-face also includes trust-building among stakeholders as well as developing a shared understanding of problems. This was also mentioned by participants, especially when they talked about spatial issues within design. However, researchers recognized that face-to-face communication in construction often requires more time than other communication channels (Cheung et al., 2013; Gorse et al., 1999). This was also found, in this dissertation, when interviewees mentioned the travel time to site and agenda issues of scheduling on-site visits. However, respondents indicated that face-to-face can be much more effective and efficient for problem solving when it is possible. Reasons presented included possibility for immediate feedback, use of gestures, reduced ambiguity, and a more personal interaction. These reasons were also mentioned by other researchers as benefits of face-to-face communication (Gorse & Emmitt, 2007; Trevino et al., 1987).

5.1.2 Telephone for fast or informal feedback

Telephone communications was also indicated as a very helpful channel in the first two phases because it provided an immediate response, despite geographical limitations of job site location or off-site designers. Trevino et al. (1987) also indicated that telephone was mostly chosen for situational reasons in their research. Gorse et al. (1999) did not find this to be the case when studying design problem-solving over multiple channels. Differences in telephone and email found in this dissertation and in Gorse et al. (1999) might be related to the improvement of mobile phone communications and a greater availability of the internet at jobsites.

Also, telephone was seen by most interviewees in phase two as an important channel for exchanging informal information or information that was explicitly not meant to be formalized. This included exchange of opinions regarding proposed solutions or implications of proposed solutions. Researchers have indicated that trust between participants in the construction process facilitates the exchange of information, especially confidential information (Cheung et al., 2013), and it improves relationships between stakeholders (Nesan, 2012). Researchers have also shown that “it appears that there is a close relationship among trust, communication, and project performance” (Cheung et al., 2013, p.941). This was evident during interviews for phase 2 in which most respondents indicated using the telephone for conversations between design and field personnel they wished to maintain ‘off the record,’ or for which they needed a fast reply.

5.1.3 Email and the need for record-keeping

Email and telephone were often mentioned as complementary, especially during interviews from phase 2. Emails were mentioned as not a good means for the start of the problem-solving process but as a way to formalize solutions and exchange visual aids (especially plans and sketches). Cheung et al. (2013) mention that email communications “is the fastest method of sending messages but it is not useful for complex communication" (p. 943). Researchers also have shown that written communications and emails are less rich than face-to-face and email (Daft et al., 1987; Trevino et al., 1987). However, the ability to attach visual information to written communications, which was mentioned several times during interviews was seen as beneficial, a fact also mentioned by Gorse et al. (1999). However, emails were not frequently used at the time Gorse et al.'s research was performed. Instead, Gorse et al. (1999) evaluated letters and faxes with visual aids attached to them.

Email, even though presented as third place in phase 1, which corresponds to findings by Trevino et al. (1987) and Daft et al. (1987), was indicated by interviewees in phase 2 as a way to keep track of information exchanged between participants. Email was seen as a good 'record keeping channel' and also as a way to formalize requests and complaints and send visual information unavailable during phone communications. The need to establish a 'paper trail' of communications is commonly known in the AECO industry due to the multitude of stakeholders who participate in the process of construction. The need for a 'paper trail' is often based on contract specifications for written notifications in order to protect parties in the case of future claims disputes (Levin, 1998; Schoenwetter & Carver, 2008). Nesan (2012) indicates that the construction industry lacks trust between participants, shown through a 'blame culture.' The content of interviews showed that most professionals use email to keep a record of information sent, including recipient and date, in case of later disputes.

On the other hand, even though emails were seen as useful for record keeping, participants often complained about the number of emails they received on a daily basis. One of the interview participants indicated that the 'email overload' caused many important emails to be overlooked or deleted. Again, fear of liability issues in the AECO industry seems to have created an inundation of emails exclusively for record-keeping purposes. Further researcher would be necessary to understand the reasons for and consequences of this 'information overload.'

However, this seems to be related to the lack of trust mentioned by other researchers (Cheung et al., 2013; Nesan, 2012).

5.1.4 The benefits of visual information

In all phases, participants mentioned that the ability to use hand gestures or look directly at the problem was most effective while discussing design problems. In the case of phase 3, only face-to-face communications allowed participants to exchange gestures, which they frequently did while pointing at spaces in their plans. This also indicates how richer means of communication, in which symbolic cues are available, are important to solve complex problems (Gorse et al., 1999; Trevino et al., 1987). The lack of gestures in telephone and email communication facilitated the existence of more miscommunications related to space for both students and professionals. Professionals in a telephone situation, especially the construction manager, seemed to be more aware of the constraints of the channel and therefore provided more specific description of spaces to the designer. However, the specificity of their language did not prevent this group from having at least one misunderstanding. The lack of visual aids indicated by Gorse et al. (1999) are more determinant than if the media used was based on verbal or written exchange. In the case of this study, even though participants were allowed to exchange images attached to the email, students and professionals chose not to do so.

This lack of visual aids created misunderstandings in phase 3. However, misunderstandings in telephone communication were rapidly identified and solved by participants. On the other hand, the lack of synchronicity of email made misunderstandings by professionals and students last for several minutes. Fox et al. (2010) have studied the effect of media synchronicity in design problem solving and indicated that “Planned synchronous communication is essential to the design, construction, and operation of buildings” (p. 60). This is especially true in an industry that requires the participation of several stakeholders who are often spread across several locations (Dave & Koskela, 2009; Fox et al., 2010; Nesan, 2012)

5.1.5 Problem-solving, media, and experience

Finally, phase 3 demonstrated that the problem-solving process organization is similar across all channels. All groups in phase 3 started with goal clarification and then moved to solution generation and analysis of each generated solution, which is coherent to findings by Stempfle and Badke-Schaub (2002). However, the results of this dissertation indicate that in a face-to-face setting, participants had more interaction and discussion than with the telephone, and even more than with email. In face-to-face and telephone communications for phase 3, analysis of generated solutions was explicit and performed as a group task. With email, the analysis of each solution was performed individually. Also, in the email setting, participants exchanged significantly less information than the other groups did. This was true for students and professionals. Due to the asynchronous nature of the channel, participants using email, even when the message was unclear, took longer to provide feedback to the sender and eliminate misunderstanding. This happened to both students and professionals, and confirms the limitations of the email channel as an asynchronous and overall poorer media (Daft et al., 1987; Fox et al., 2010; Trevino et al., 1987).

Even though communication patterns in phase 3 seemed to vary more by channel than by experience, the professionals' exchanges in face-to-face and telephone settings were different than the students' exchanges. The little amount of information exchanged through email does not allow this researcher to indicate differences in content for this channel. But in face-to-face and telephone interactions, professionals did present more experience as problem-solvers in the design and construction industry. Professional experience translated into identifying important constraint information and conceptualizing possible solutions, based on previous experiences. This is consistent with research indicating that construction professionals are aware of the influence of change on budget and schedule (Thomson et al., 2006). It is also suggests use of tacit knowledge acquired through years of full time experience, which is common in the construction industry (Dave & Koskela, 2009; Nesan, 2012).

Students' approaches, on other hand, were based either on trial and error in the case of face-to-face or selecting the first and only solution in the case of telephone communication. Research on expertise indicates that this trial and error approach and the failure to identify important information in constraints are characteristic of beginners (Bryson et al., 1991; Thomson et al., 2006).

Also, the collaboration between designers and construction managers during the problem-solving process was mostly beneficial. The students' case of face-to-face interaction explicitly showed how both participants learned from each other through inquiry and debate when the proposed solution was inadequate for one of the participants. Research on problem solving in multidisciplinary situations indicates that this information exchange among participants is a way to align goals, build sharing understanding, and improve solution generation (Dorst & Cross, 2001; Sonnenwald, 1996; Stempfle & Badke-Schaub, 2002). However, these positive results were not as present in the telephone interaction between students. Further studies replicating this quasi-experiment could provide more insight about professionals' and students' differences while solving these types of design problem within a construction context.

5.2 Conclusions

Based on the results obtained and the review of previous literature about the influence of choice of media on problem-solving in construction communications, the author concludes:

- From the six media channels surveyed in phase 1 (face-to-face, telephone, email, text messaging, videoconferencing, and online instant messaging), the top three most helpful channels selected by professionals were face-to-face, telephone, and email. This is consistent with literature and also confirmed by the phase 2 interviews;

- Face-to-face is still the most preferred and one of the most helpful ways to communicate between parties regarding design problems with spatial information. Advantages of face-to-face communication include the ability to supplement verbal communication with non-verbal cues and visual aids. However, use of face-to-face communications between site and supervision personnel during construction is diminished due to difficulties in scheduling and accessibility to the site or the office of project stakeholders;

- Telephone communication is often used as an alternative to face-to-face communications, and its main advantage is the possibility of immediate feedback from the other party. Another frequently mentioned use for the telephone is to mediate intentionally informal conversations between parties during the problem-solving process. Limitations of this channel include the inability to convey visual information and the lack of a written record preserving what was discussed;

- Email is seen ss the third most helpful channel of communication in construction for design issues with spatial information. The main issue with this channel is that it is not a synchronous channel, which may result in delays in communication. Email overload resulting in missed communication was also mentioned as a problem for making email a reliable communication for urgent messages;

- The need to establish a 'paper record' of communications was mentioned by interviewees as an important factor influencing the decision of which channel to use. Email was considered by participants as a good channel for establishing that record;

- Channel limitations seem to influence communication patterns and frequency more than experience, however more studies should be performed to confirm this trend. Expertise seems to have a broader influence on the explicit and implicit information content and how the problem is approached by participants. Solutions proposed by professionals often require smaller changes in layout and space configuration than the ones proposed by students. Students also seem to be less aware of possible consequences of proposed solutions on the design. However, active collaboration of both the design and site supervision participants was shown to be improve participants' understanding of those consequences and allowed for an improved learning experience.

Conclusions based on phase three are limited by the reduced number of participants but still provide guidance for future research on media influence on problem solving and inquiries into how participants build their knowledge based on peer feedback.

Based on the conclusions provided above, and in order to produce a tangible product for this dissertation, the author has developed effective communication guidelines that will be presented in the next section.

5.2.1 Guidelines for effective communication

Guidelines for effective communication between design and site supervision personnel regarding design problems with spatial information were developed as a product of this dissertation. They were developed by the researcher based on the results and discussion of all phases. The draft guidelines were presented to one faculty member of the School of Construction Management (CM) of Purdue University and one faculty member of Computer Graphics Technology (CGT). Both faculty have professional experience in their field of expertise. Appendix F presents the questions posed to each faculty. Interviewees were conducted either in person (in the case of the CM faculty) or by phone (CGT faculty) and lasted 14m32s and 26m04s respectively.

The following paragraphs present the final version in the form of tips for effective communication.

Guidelines for effective communication between design and site supervision personnel:

Channels: Channels are means of communicating information between people. For the purposes of this document, channels are face-to-face, telephone, email, videoconferencing, text message, or email.

Tip #1: *When selecting a channel to communicate an issue, evaluate if the chosen channel is easily accessible to the receiver of the message.*

If you prefer face-to-face, would this be a possibility for all involved or would it involve delays and extra costs due to traveling to the meeting location? If you prefer phone, consider if the receiver of the call would be easily available to answer the call or to call you back. In the case of email, consider whether there is a chance your receiver may overlook your message due to email overload. If necessary, a combination of more than one channel should be used. For example, after sending an email, evaluate the need to make a call to confirm the receiver has opened the message. Especially with email, it is important to separate the act of 'sending a message' from the act of 'receiving a message.' Finally, when using other means of communication, make sure your receiver has accessibility and usability for those channels.

Tip #2: *When selecting a channel to communicate an issue, decide whether there is the need for a 'paper trail' during conversation or through a follow-up, or whether it is better to maintain an informal discussion.*

When choosing which media to use, consider if you need to formalize information or if you specifically need to not formalize the discussion. Remember that it is always good practice to formalize a discussion, not only because litigation may occur in the future but also in the case of personnel change in the middle of a project. As for choice of channels, keep in mind that telephone is better for an informal discussion or 'heads up,' while email is good for keeping track of what was sent, to whom, and when. There is an inherent lack of trust between stakeholders in the industry, and choosing your channel should take this issue into account. When using a channel that is not good for record keeping due to other reasons, consider following up with a summary email. This should be done even if you think all participants understood and are aware of what was discussed.

Tip #3: *Use multiple communication cues when possible.*

If you are using a channel that allows for multiple forms of communication such as tone of voice, gesture, or visual aid, take advantage of those forms. For example, if you are talking face-to-face, your body language and gestures can add extra layers of information to the receiver, which can help them understand your message. In telephone communications, your tone of voice may help the receiver understand the gravity of the situation.

Tip #4: *Use more precise descriptions when you are not talking face-to-face.*

If restricted to using a channel of communication that does not allow for visual content (such as telephone) or immediate feedback (such as email), then try being more precise in your descriptions. Instead of using ambiguous expressions such as 'next to' or 'near,' use less ambiguous expressions such as 'to the left of…'. Also, establish reference points that are easily understood and located by your peer. A good reference point should be unique, such as a room number or a specific name.

Tip #5: *Take advantage of real time conversations to check for intermediate feedback by the receiver.*

If your channel allows for immediate feedback, such as face-to-face and telephone communications, take advantage of that to constantly check if the receiver of your message is understanding the issue. If you have established and communicated a reference point, ask for feedback to verify if you both have the same reference point in mind. If you have explained an idea that includes spatial information, make sure that between chunks of spatial information you ask for feedback to see if your peer is following the idea. This way, if miscommunication happens, you will only have to review the part that you are sure to be misunderstood and not the entire communication.

Tip #6: *When in doubt about the message, ask and do not assume.*

If you are the one receiving information and have doubts about the message, instead of letting your peer continue to develop the dialogue (in case of face-to-face or telephone communications) or just waiting for an answer (in case of email), be sure to ask questions. It is much easier to fix a misunderstanding if it is caught early.

Tip #7: *When you disagree with a solution, ask for the reasons behind your counterpart's reasoning and state your own reasons for your disagreeing.*

Something that may be an obvious issue for your discipline might not be so obvious for others. In order to understand if an argument is valid, it is important to evaluate the reasoning behind it before ruling it out. If after a broader explanation you still disagree, state your reasons to your peer so they are aware of why you disagree. Learning about each other's reasoning can help develop better solutions and avoid time spent on proposals that will not be considered by both parties. Also, be prepared to 'agree to disagree' in certain situations when a delay in reaching a solution may negatively affect the overall project and construction development.

Tip #8: *When understanding is difficult, try switching channels or providing extra visual aids.*

Sometimes, the cause for miscommunication might be related to the choice of channel. If too many emails are bounced back and forth, or if during a phone call you really cannot understand what the issue is, consider switching means of communication. Evaluate what you consider to be the advantages and disadvantages of each means of communication available and if a transition would help. Maybe immediate feedback provided in a phone conversation would speed up the results from a chain of unsuccessful emails, or maybe scheduling an on-site meeting despite everyone's busy schedules is what it will take to make a complex design decision.

Tip #9: *Even when the message is urgent, take time to make sure your receiver understands the setting and the issue in hand.*

Making sure all stakeholders involved in an issue know the constraints and limitations of the problem may avoid unnecessary discussion and the proposal of impossible solutions. Once the job starts, the information available for decision making includes not only the design but also the scheduling and budget constraints. This information is normally unavailable to the designer, unless the construction manager makes this explicit to all involved. Also, other constraints specific to other stakeholders may exist, such as design constraints made by the owner which are now embedded in the design but, similarly, are not explicit to all involved.

Tip #10: *Evaluate advantages and disadvantages of each channel. Sometimes more than one channel of communication is necessary for effective communication.*

Finally, evaluate what you consider advantages and disadvantages of each channel of communication. Table 5.1 shows what the author of these guidelines has found to be the advantages and disadvantages of face-to-face, telephone, and email communications in the AECO industry. Knowing those characteristics may help to evaluate the reasons for a message not being effectively received. In most situations, a combination of channels will be necessary to solve an issue, and taking advantage of each channels' strengths and minimizing its weaknesses is an important skill for effective construction communication.

Table 5.1
Guidelines for channel advantages and disadvantages

Face-to-face	
Advantages	Disadvantages
May use tone of voice cues and visual aids; Real time feedback; Allows for timely emotional support if needed (more personal); Reduced message ambiguity.	Potential emotional interactions in meetings may be undesirable Schedule availability; Lack of written record (if there are no minutes); May not allow time for thorough reflection.
Telephone	
Advantages	Disadvantages
Real time feedback; May use tone of voice cues; Good for informal conversations; Good to convey urgency.	Depends on receiver's availability; No written record; Difficult to convey visual information; May be disruptive to work.
Email	
Advantages	Disadvantages
Does not depend on receiver's availability; Written record; Less charged with emotions; Allows visual aid attachments; May be accessed through several different gadgets; Allows time for reflection.	Impersonal, may lead to misunderstandings; Email overload; Writing effective emails may take time; Less effective to older generations. Lack of real time feedback may cause delays in communication;

As one can see, ten tips and the table containing advantages and disadvantages would be part of the guidelines, which should be used to help students and young professionals to evaluate and improve communication between project stakeholders. However, the effectiveness of these guidelines have not been tested. Further studies on the use of these guidelines could provide feedback for their improvement and application in the construction industry.

During the interview to review the draft guidelines, both faculty mentioned that the findings accurately represent their industry experience. They also mentioned that communication issues between parties was a current issue during their professional lives. Both have mentioned switching channels from poorer to richer channels as a strategy to reduce misunderstandings, especially when time restrictions and availability constraints applied. The CM faculty mentioned that problem complexity was also a key factor for determining which channel to use during problem solving. Contrary to the findings from phase 1, the CGT faculty member mentioned lately seeing an increase in the use of videoconferencing among colleagues from the design side. The use of this channel is seen as a way to overcome the distance between stakeholders, preserve the visual cues of a face-to-face interaction, and provide a record (as videoconferences may be recorded).

Interestingly, both participants mentioned that they perceive a generational gap between current undergraduate students and older professionals in terms of communication patterns. This generation gap is present for both interviewees in their industry's communication. However, the CGT faculty mentioned that personality traits seem to be more important than generational differences in determining the comfort level a person has with a channel. This perception is different than what other researchers have found, namely, that in which millennials still prefer to use more well-established means of communication for work purposes (Friedl & Verčič, 2011; Kurkovsky & Syta, 2010).

The professors offered specific comments regarding the rewording of certain tips, especially distinguishing between the words 'synchronous' and 'asynchronous.'

Both professors indicated that students or young professionals might not be aware of what these words mean. Also, in relation to tip # 2, both faculty mentioned that students should be made aware that a 'paper trail' is a necessity in construction and that students should always follow up even with telephone conversations and face-to-face meetings. The CGT faculty also recommended including in tip #9 that conflict is common in construction and that sometimes it is in the best interest of all to 'agree to disagree' so that the project can be completed. The CM faculty suggested reviewing the word 'channel' in order to facilitate understanding among students and young professionals. However, the researcher evaluated other words and did not find one that could satisfactorily convey the same meaning. Therefore, the researcher provides a brief definition of the word 'channel' before the tips begin.

Finally, both faculty indicated that, overall, they agree with the tips and think this type of guidance to students and young professionals may be very beneficial. Based on the interviews, the researcher reviewed the proposed guidelines.

5.3 Limitations

Some unexpected limitations were found during the course of this dissertation, as mentioned in Chapter 1 (Introduction) of this document. The summary below indicates limitations per each phase of the work:

- *Phase 1*: Results presented in phase 1 might be limited due to the low response rate (5%);
- *Phase 1*: No respondents of phase one worked in the East South Central Region (AL, KY, MS, TN);
- *Phase 1*: The channel email obtained a lower than ideal internal consistency ($\alpha < 0.70$);
- *Phase 1*: Many participants did not provide answers for all questions in the survey;

- *Phase 2*: Due to connectivity issues, two participants who wished to have a video conference for the interview were forced to use only audio;
- *Phase 3*: Due to connectivity issues, the PVST:ROT test was not used for pre-qualification but as a factor for analysis and was given during the task meeting;
- *Phase 3*: The researcher had to expand the sample population to encompass graduate students with little or no industry experience because of the very low response rate for design students;
- *Phase 3*: The researcher had to expand the sample population to include students from Computer Graphics Technology (with emphasis on Building Information Modeling), due to the lack of response from Interior Design undergraduate students from Purdue University;
- *Phase 3*: The researcher ideally planned for three repetitions for each variable combination of phase three. However, due to the low response of students and professionals during the course of three months, the researcher opted for the quasi-experiments, and, given the results already obtained from previous phases, the researcher opted to proceed with only one test for each variable combination;
- *Phase 3*: Most of the analysis for this phase was performed using the video because there was only one researcher to accompany the two participants as well as perform administrative tasks (time keeping and overseeing video).

5.4 Recommendations for Future Studies

This study has provided some answers, but it also raises questions that could be addressed through further research. Some suggestions that could improve our understanding of communication media in the AECO industry as well as problem solving and spatial information are:

- *Quantification of losses caused by misunderstandings in construction*: In order to attract attention to the importance of improving communication, it would beneficial to understand losses caused by inefficient communication in construction. The development of a metric and the collection of data in the industry would provide an important baseline for comparing future improvements;

- *Information overload in construction*: One of the interviewees mentioned being overloaded by emails, and this is one of the reasons many of the interviewees indicated that often times emails get lost or 'dropped.' It would be beneficial to understand the amount of information an average professional in construction processes per day to understand if overload could be one of the reasons that cause miscommunications;

- *Development and evaluation of communication training for students and young professionals*: It would be interesting to verify if the guidelines for effective communication contained in this chapter would provide improvement for the communication of students and professionals in construction regarding design issues. Future evaluation by end users could provide refinement of the guidelines into a commercial training that could be used by companies or universities to train students in best communication practices;

- *Better understand how trust defines the choice for formal and informal communication between parties in construction*: Trust and liability issues were often mentioned, especially during the interviews, as defining which media professionals would choose to communicate. Cheung et al. (2013) and Nesan (2012) mentioned the importance of trust to establish better communications. It would be interesting to understand the processes at the individual and at the company level that guide the choice for formal or informal communication between parties, especially regarding design issues, which are often treated by parties between separate companies;

- *The rise of new communication and information technologies in construction*: First phase results indicate a large standard deviation for videoconferencing for both design and construction personnel. Further studies may provide the reasons for this, as well as help understand the role and usage of new communication technologies or technologies that facilitate information transfer within the AECO industry, such as Building Information Modeling;

- *Trend of PSVT:ROT scores over time for CM professionals*: Overall, students' performance on the PSVT:ROT test was much superior than that of professionals, though their success in the quasi-experiment task was not. It would be interesting to understand how the PSVT:ROT scores evolve over the years after graduation. It would also provide important data regarding the validity of this test for its use to assess professionals' spatial ability skills. Most professionals in this quasi-experiment could not finish providing answers to all 30 questions in the test. Most published studies which have used the PSVT to assess spatial ability were in a university or college setting and included students (mainly engineering) as their subjects, such as the ones by Yoon (2011) and Bodner and Guay (1997).

5.5 Summary

In this dissertation, the author proposed to study how the choice of media influences the problem solving process in construction, with a special emphasis on design issues with spatial information. Through the three phases performed, the researcher answered the following specific questions: (a) Which are the main media of communication between site and design teams when reporting spatial problems related to design? (b) What are the advantages and disadvantages of each of the most helpful media? (c) What are the perceptions about effectiveness, difficulty, and strategy students and professionals in construction related fields have about the main media of communication? Results for these questions were presented in chapter 4.

In this chapter, the researcher evaluated how findings from this dissertation related between each of the phases and to previous literature. Based on the discussion generated from this evaluation, the researcher made conclusions about issues related to the main questions of this dissertation ('How does choice of media influence problem solving in construction communications?'). These conclusions were used to create brief guidelines for improving communication efficiency. These guidelines are mainly focused on students and young professionals who have not yet acquired a broad tacit knowledge about the construction communication. The proposed guidelines, which took the form of ten tips, were reviewed by faculty of construction management and design, and comments made by interviewees were used to refine the proposed tips.

During the course of this study, some limitations were added to those expected at the beginning. These limitations are presented so that readers are aware of how the results may have been influenced. All generalizations made in response to this study must take into account the researcher's limitations, delimitations, and assumptions.

Finally, recommendations are made for future studies that could draw from the knowledge produced by this work. It is expected that this dissertation will help to grow the body of knowledge about construction communication and design problem-solving in the AECO industry. Even though the research questions proposed in this study were answered, many more have emerged. Future contributions would help elucidate some of these emerging questions and improve the way we communicate and solve problems in construction, contributing to the development of the AECO industry as a whole.

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APPENDICES

Appendix A: Draft Questionnaire for phase 1

[To be entered later in Qualtrics]

(Introduction) This survey is aimed at members of the architectural design team and site supervision professionals that interact with each other during their normal work routine. We want to understand how informal communication happen between these two different areas. We want to know which channels (meetings, emails, telephone and others) they use when talking about design problems occurring during the construction stage. This survey does not focus on formal documents such as change orders and requests for information, but on more informal means of communication between construction professionals. We want to know what happens when time is of essence and a solution must be presented fast. This survey will help us by informing about the construction industry reality, when it comes to informal means of communication.

If you choose to participate in this survey by clicking 'next' on the lower side of the screen, know that your information will be collected anonymously. You and your company will not be identified.

To answer this survey you should take average 10 minutes or less.

Thank you for your time and participation!

[first screen]

Part 1: Role definition

About your role in the company

1) With which role in construction do you mostly identify (select one)?

☐ Member of the design team that interacts with site supervision personnel

☐ Member of the design team that does NOT interact with site supervision personnel

☐ Member of site supervision team that interacts with the design team

- ☐ Member of site supervision team that does NOT interact with the design team
- ☐ Neither a member of the design team, nor site supervision team

[second screen]

Part 2: Cases

(if field personnel) For both cases, please consider that you are in the field and need to talk to one of the architectural or engineering design personnel. In your answer, consider that you need to answer urgently. You need to take action and cannot wait for filing a formal request for information or change order at the time. Also consider possible constraints you encounter in your daily life in the field.

[third screen]

Case 1:

You are in the field and your workers call you because they are having problems to fit all pipes within the space specified in the construction drawings due to unforeseen conditions. You need to understand why this happened and find a quick solution to keep up with the work schedule. After going over all construction documents available, you decide to communicate directly with design personnel for causes and possible solutions.

2) Please indicate how helpful are each of the following communication channels in this situation:

a Face to face:

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

b Videoconferencing (e.g.: calls made with Skype, Facetime, Hangouts with video feature ON):

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

c Telephone (e.g.: calls made with telephone, cell phone or Skype, Facetime, Hangouts with video feature OFF):

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

d Online instant messaging (e.g.: using chat features by Skype, Facetime, Hangouts or chat feature on corporate email):

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

e Text message (e.g.: sms, text messages via your wireless carrier, to another phone):

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

f Email (e.g.: email via computer, tablet, laptop, or mobile):

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

3) Please rank from 1(most helpful) to 6(least helpful) the following channels for this problem:

Videoconferencing: ____

Email: ____

Telephone: ____

Face to face: ____

Text message: ____

Online instant messaging: ____

4) Could you provide more comments about your choices?

____

____

____

____

[fourth screen] Case 2:

You are in the field and your workers call you because they are having problems locating some power outlets because of the window sill heights. You have some options to fix this, such as rotating, dislocating, or simply changing the heights. You need to discuss this with the design department in order to find a solution that does not interfere with design standards and specifications previously approved by the client. You are already late on schedule, and you need to make a decision fast.

5) Please indicate how helpful are each of the following communication channels in this situation:

a Videoconferencing (e.g.: calls made with Skype, Facetime, Hangouts WITH video feature on):

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

b Online instant messaging (e.g.: using chat features by Skype, Facetime, Hangouts or chat feature on corporate email):

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

c Text message (e.g.: sms, text messages via your wireless carrier, to another phone):

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

d Face to face:

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

e Email (e.g.: email via computer, tablet, laptop, or mobile):

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

f Telephone (e.g.: calls made with telephone, cell phone or Skype, Facetime, Hangouts with video feature OFF):

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

6) Please rank from 1(most helpful) to 6(least helpful) the following channels for this problem:

Face to face: ____

Telephone: ____

Videoconferencing: ____

Email: ____

Text message: ____

Online instant messaging: ____

7) Could you provide more comments about your choices?

____

____

____

____

[second screen]

Part 2: Cases

(if design personnel) For both cases, please consider that you are in the office and need to talk to site supervision professionals. In your answer, consider that you need the answer urgently so to contact other designers to conduct and start the change order or request for information processes . Also consider possible constraints you encounter in your daily life when talking to professionals on site.

[third screen]

Case 1:

Your client went to the field and complained that the ceilings were not placed according to previously approved architectural drawings and specifications. He did not mention which, but just that they were close to the main building entrance. You need to confirm with site personnel which ceilings were built, and make sure the heights and design in accordance with the specifications.

2) Please indicate how helpful are each of the following communication channels in this situation:

a Face to face:

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

b Videoconferencing (e.g.: calls made with Skype, Facetime, Hangouts WITH video feature on):

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

c Telephone (e.g.: calls made with telephone, cell phone or Skype, Facetime, Hangouts with video feature OFF):

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

d Online instant messaging (e.g.: using chat features by Skype, Facetime, Hangouts or chat feature on corporate email):

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

e Text message (e.g.: sms, text messages via your wireless carrier, to another phone):

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

f Email (e.g.: email via computer, tablet, laptop, or mobile):

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

3) Please rank from 1(most helpful) to 6(least helpful) the following channels for this problem:

Videoconferencing: ____

Email: ____

Telephone: ____

Face to face: ____

Text message: ____

Online instant messaging: ____

4) Could you provide more comments about your choices?

___

___

___

___

[fourth screen] Case 2:

After a design meeting, there is a decision to change the sizes of some structural beams (height and width) due to structural redefinition of the project. Construction is on schedule and site crew might have already erected some of these beams on site. You need this information fast in order to define a plan of action. You need to contact field personnel to find this out urgently.

5) Please indicate how helpful are each of the following communication channels in this situation:

a Videoconferencing (e.g.: calls made with Skype, Facetime, Hangouts WITH video feature on):

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

b Online instant messaging (e.g.: using chat features by Skype, Facetime, Hangouts or chat feature on corporate email):

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

c Text message (e.g.: sms, text messages via your wireless carrier, to another phone):

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

d Face to face:

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

e Email (e.g.: email via computer, tablet, laptop, or mobile):

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

f Telephone (e.g.: calls made with telephone, cell phone or Skype, Facetime, Hangouts with video feature OFF):

Unutilized |Of little help |Moderately Helpful |Helpful |Very Helpful

6) Please rank from 1(most helpful) to 6(least helpful) the following channels for this problem:

Face to face: ____

Telephone: ____

Videoconferencing: ____

Email: ____

Text message: ____

Online instant messaging: ____

7) Could you provide more comments about your choices?

____

____

____

____

[fith screen]

Part 3: Demographics

About your company

8) Where is your current work location?

☐ Pacific (AK, CA, HI, OR, WA)

☐ Mountain (AZ, CO, ID, MT, NM, NV, UT, WY)

☐ West North Central (KS, IA, MN, MO, ND, NE, SD)

☐ East North Central (ID, IN, MI, OH, WI)

☐ West South Central (AR, LA, OK, TX)

☐ East South Central (AL, KY, MS, TN)

☐ South Atlantic (DC, DE, FL, GA, MD, NC, SC, WV)

☐ Middle Atlantic (NJ, NY, PA)

☐ New England (CT, MA, ME, NH, RI, VT)

9) How many employees do you estimate exist overall in your company?

☐ 1 - 9

☐ 10 - 49

☐ 50 - 249

☐ 250 - 999

☐ 1,000 - 4,999

☐ 5,000 or plus

10) What type of construction or design does your company do?

a Hospitality (Hotels, motels and amusement facilities): ☐ Yes ☐ No

b Warehouses and Manufacturing Buildings: ☐ Yes ☐ No

c Institutional: ☐ Yes ☐ No

d Healthcare Facilities and Laboratories: ☐ Yes ☐ No

e Heavy Civil (Highway, Brides, Electric Power, Gas, Communications and Water Resources): ☐ Yes ☐ No

f General Commercial (Office, Banking, Public, or Religious buildings): ☐ Yes ☐ No

g Residential; ☐ Yes ☐ No

h Retail Construction: ☐ Yes ☐ No

i Open or Recreational Spaces: ☐ Yes ☐ No

About you

11) How many years of professional full time experience do you have (enter number):____

12) In general, rank from 1 to 6 the communication channels that you prefer to use when you need to reach someone for PROFESSIONAL reasons:

Face to face: ____

Telephone: ____

Videoconferencing: ____

Email: ____

Text message: ____

Online instant messaging: ____

13) In general, rank from 1 to 6 the communication channels that you prefer to use when you need to reach someone for PERSONAL reasons:

Videoconferencing: ____

Text message: ____

Telephone: ____

Email: ____

Face to face: ____

Online instant messaging: ____

14) On average, how often do you communicate (formally and informally) with site supervision (if design personnel) / architecture or engineering design professionals (if you are in the field)?

☐ Less than once a week

☐ Once or twice a week

☐ Every other day

☐ Once a day

☐ More than once a day

15) How old are you?

☐ 18 - 24

☐ 25 - 29

☐ 30 - 39

☐ 40 - 49

☐ 50 - 59

☐ 60 - 69

☐ 70 or more

16) Please enter your gender (select one):

☐ Male

☐ Female

☐ Prefer not to say

17) What is your highest educational degree (select one):

☐ High school

☐ College

☐ Mba

☐ Master

☐ PhD

18) *(if college or greater)* What is your construction related major? Select the one that closest match.

☐ Architecture

☐ Landscape Architecture

☐ Interior Design

☐ Civil Engineering

☐ Construction Management

☐ Architectural Engineering

☐ Other: ____

19) If you wish to be contacted later for a follow up interview related to communication issues between site supervision and architecture and engineering design personnel, please provide a contact email: ________________

[sixth screen]

Thank you for completing this survey! Your input is very important for us.

Appendix B: Draft Interview Questions for Phase 2

(Introduction) This interview is aimed at understanding how the process of problem solving between architecture / engineering design and site teams happen in construction, through use of informal channels. This study does not focus on formal means of reporting problems, such as requests for information (RFI) or change orders (CO). The researcher wants to understand how different media interfere in this process, and what strategies are used by professionals to overcome difficulties in understanding, prior to filing formal documentation. Based on previous survey findings conducted by the researchers, the three main channels used for communicating informally in order to solve design problems during construction phase are face to face, telephone, and email. The researcher will ask you some questions about your work process and interaction with (design or field) personnel. Then the interviewer will ask you about general problem solving in your area. Finally, specific questions will be asked regarding your experience in using means face to face, telephone, and email. Your participation is important in order to better understand constraints that may appear that were not previously identified by the literature review. Thank you for your time and participation!

Part 1: Normal work process

1) What is your work title?

2) How long have you been in this company? And in this position?

3) What are your main responsibilities? Could you describe a typical work day?

4) How do you normally receive/give design information?

5) How often do you communicate with design/field personnel per week?

6) How is that communication done (which channel is used)?

7) What are examples of regular information that you exchange with design/field personnel?

Part 2: General Problem solving

8) How often do you have to deal with unexpected problems in work (managerial or logistics, not related to design-field interaction)?

9) Could you describe one of the recent issue you have faced?

10) How did you solve it?

11) Did you seek help? If so, how? Which channels did you use?

12) Did you find a channel to be more helpful than others? Why?

13) If you were given the same problem again now, how would you solve it? Would you change your approach?

14) What do you think you have learned with this problem?

Part 3: Design problem solving

15) How often do you encounter design problems during work? or How often do you encounter design problems in your work that require talking to field personnel?

16) How many of those problems must be solved urgently?

17) Could you describe some common problems (one to three) you have experienced that require design field interaction?

18) How did you solve them?

19) What channels did you use to communicate with design/field personnel in order to solve the problem?

20) Did you seek help of others other than design / field personnel? If so, how? Which channels did you use?

21) Did you find a channel to be more helpful than others? Why?

22) If you were given the same problem again now, how would you solve it? Would you change your approach?

23) Could you describe a time when you had to change the channel used because communication was not effective? If so, could you describe it?

24) The main media channels for design problems communication between design and field personnel obtained by the researchers survey results are: face to face, telephone, email. What do you think of these findings? Do you agree? Disagree? Why?

25) Could you describe in which situations you would use face to face? Why? What are some advantages and disadvantages of its use in case of design problems?

26) Could you describe in which situations you would use telephone? Why? What are some advantages and disadvantages of its use in case of design problems?

27) Could you describe in which situations you would use email? Why? What are some advantages and disadvantages of its use in case of design problems?

Part 4: Demographics

About your company

28) Where is your current work location (City, State)? 159pt1pt

29) How many employees do you estimate exist overall in your company?

☐ 1 - 9

☐ 10 - 49

☐ 50 - 249

☐ 250 - 999

☐ 1,000 - 4,999

☐ 5,000 or plus

30) What type of construction or design does your company do?

a Hospitality (Hotels, motels and amusement facilities): ☐ Yes ☐ No

b Warehouses and Manufacturing Buildings: ☐ Yes ☐ No c Institutional: ☐ Yes ☐ No

d Healthcare Facilities and Laboratories: ☐ Yes ☐ No

e Heavy Civil (Highway, Brides, Electric Power, Gas, Communications and Water Resources): ☐ Yes ☐ No

f General Commercial (Office, Banking, Public, or Religious buildings): ☐ Yes ☐ No

g Residential; ☐ Yes ☐ No

h Retail Construction: ☐ Yes ☐ No

i Open or Recreational Spaces: ☐ Yes ☐ No

About you

31) How many years of professional full time experience do you have (enter number):____

32) How old are you?

☐ 18 - 24

☐ 25 - 29

☐ 30 - 39

☐ 40 - 49

☐ 50 - 59

☐ 60 - 69

☐ 70 or more

33) Enter gender (select one):

☐ Male

☐ Female

34) What is your highest educational degree (select one):

☐ High school

☐ College

☐ Mba

☐ Master

☐ PhD

35) *(if college or greater)* What is your construction related major? Select the one that closest match.

☐ Architecture

☐ Landscape Architecture

☐ Interior Design

☐ Civil Engineering

☐ Construction Management

☐ Architectural Engineering

☐ Other: ____

Appendix C: Draft Questionnaire for Phase 3

Thank you! You have just completed a problem solving task using one of the following communication media:

☐ Face to Face

☐ Telephone

☐ Email

Your role on this task was:

☐ Design

☐ Site supervision

You are a:

☐ Student

☐ Professional

Please take a moment to reflect on the task before answering the following questions.

About the task

1) Please describe what was your team's approach to the task in your words (more space also available on the other page):

____

____

____

____

2) How difficult was the task, overall?

Very easy |Easy |Undecided |Hard |Very Hard

3) How satisfied are you with your solution?

Very unsatisfied |Unsatisfied |Undecided |Satisfied |Very Satisfied

4) If given another chance, what would you do differently?

5) How was the interaction with your peer?

Terrible |Bad |Undecided |Good |Excellent

6) Please provide any comments you wish to note about your peer interaction.

7) What did you think about the channel you used for this task? Do you think it had constraints? If so, which? Give examples.

8) Do you believe you were misunderstood at any point during the task?

☐ Yes ☐ No

If yes, indicate the situation (s).

9) Do you believe you misunderstood your peer at any point during the task?

☐ Yes ☐ No

If yes, indicate the situation (s).

10) If misunderstandings occurred in the task, explain how you and your peer overcame these difficulties.

____

____

____

____

Demographics

[if industry]*About your company*

[if industry] 11) How many employees do you estimate are employed by your company?

- ☐ 1 - 9
- ☐ 10 - 49
- ☐ 50 - 249
- ☐ 250 - 999
- ☐ 1,000 - 4,999
- ☐ 5,000 or plus

[if industry] 12) What type of construction or design does your company do?

a Hospitality (Hotels, motels and amusement facilities): ☐ Yes ☐ No

b Warehouses and Manufacturing Buildings: ☐ Yes ☐ No

c Institutional: ☐ Yes ☐ No

d Healthcare Facilities and Laboratories: ☐ Yes ☐ No

e Heavy Civil (Highway, Brides, Electric Power, Gas, Communications and Water Resources): ☐ Yes ☐ No

f General Commercial (Office, Banking, Public, or Religious buildings): ☐ Yes ☐ No g Residential; ☐ Yes ☐ No

h Retail Construction: ☐ Yes ☐ No

i Open or Recreational Spaces: ☐ Yes ☐ No

About you

[if industry] 13) How many years of professional full time experience do you have (enter number):____

[if student] 14) How many months of internship experience do you have:

☐ Full time: ____

☐ Part time: ____

[for industry and students] 15) In general, rank from 1 to 6 the communication channels that you prefer to use when you need to reach someone for PROFESSIONAL reasons:

Face to face: ____

Telephone: ____

Videoconferencing: ____

Email: ____

Text message: ____

Online instant messaging: ____

[for industry and students] 16) In general, rank from 1 to 6 the communication channels that you prefer to use when you need to reach someone for PERSONAL reasons:

Videoconferencing: ____

Text message: ____

Telephone: ____

Email: ____

Face to face: ____

Online instant messaging: ____

[for industry and students] 17) How old are you?

☐ 18 - 24

☐ 25 - 29

☐ 30 - 39

☐ 40 - 49

☐ 50 - 59

☐ 60 - 69

☐ 70 or more

[for industry and students] 18) Please enter your gender (select one):

☐ Male

☐ Female

☐ Prefer not to say

[for industry and students] 19) What is your highest educational degree (select one):

☐ High school

☐ College

☐ Mba

☐ Master

☐ PhD

[for industry and students] 20) What is your construction related major? Select the closest match.

- ☐ Architecture
- ☐ Landscape Architecture
- ☐ Interior Design
- ☐ Civil Engineering
- ☐ Construction Management
- ☐ Architectural Engineering
- ☐ Other: ____

Thank you for completing this task and questionnaire!

If you have any additional comments you wish to make pertaining to this research, please indicate below:

____

____

____

____

Appendix D: Phase 3 Case

Protocol for Phase 3 case:

- To both participants: : You have 3 minutes to take a quick look at the plans. Please do not mark the plans.
- To CM: You may take notes of this if you wish, however you will receive a printed copy of this message.

    You are the construction project manager for this project. You are on site and the data equipment company came to inspect your construction. They asked to look at the drawings and did a tour of the site. Youve just finished erecting your structure. They said to you that they cannot have any pipes passing over the data room (HVAC ducts are okay). Plumbing installation will start in 2 weeks and all the material has been ordered already. The plumbing engineer said he is willing to change drawings, but he wants you to talk to the architect first and propose a solution for him to work with.
    Two things you remember are that (1) gear lockers in the adjacent wall are floor to ceiling, and the fire station does not allow for soffits inside lockers. (2) both floor layouts have been approved by the client for months, and there is a strict requirement only for the first floor layout not to change. (give CM a printed version of the message).

    Please talk / call / email the architect and find a solution to this problem. The architect does not know about the issue and you must explain it to him/her.

- To Architect (given in print): You are the architect of the project. Two things you remember about this project are that: (1) Gear lockers in the adjacent wall are floor to ceiling, and the fire station does not allow for soffits inside lockers. (2) Both floor layouts have been approved by the client for months. And there is only a strict requirement only for the first floor layout not to change.

- To both participants: You have 15minutes to solve the issue and write up a solution in a blank sheet of paper. Do not write on the plans. I will let you know when you reach the 12min mark and I suggest start working on writing the solution. When 15min is up, Ill let you know and you will have to stop working.

The following images show the two floors for the building used as setting for this research, as well as the plumbing on top of the data room.

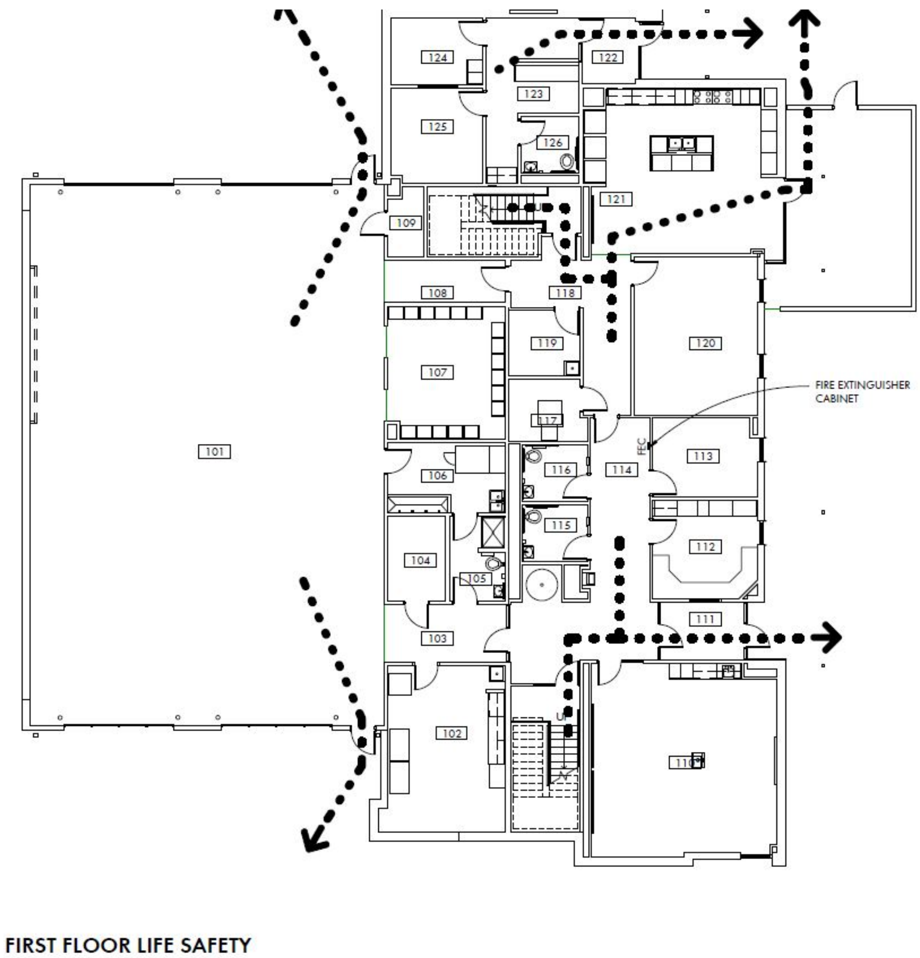

Figure D.1. First Floor plan for building used as setting for phase 3 case

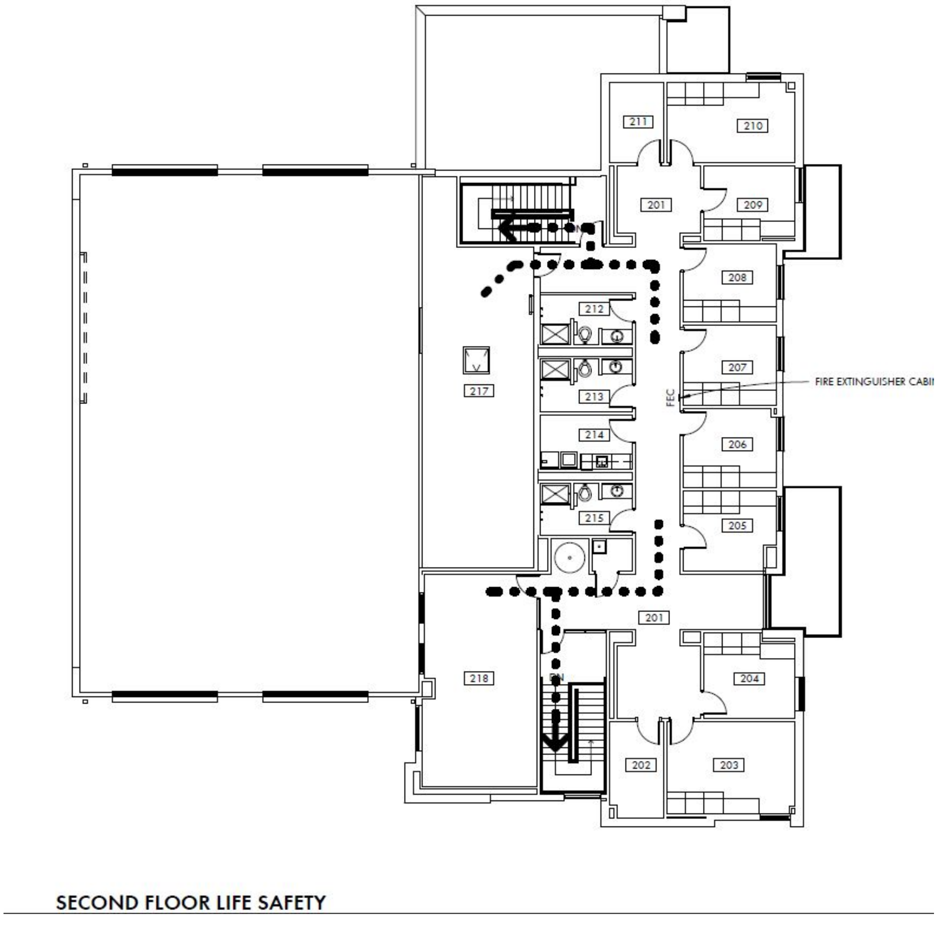

Figure D.2. Second Floor plan for building used as setting for phase 3 case

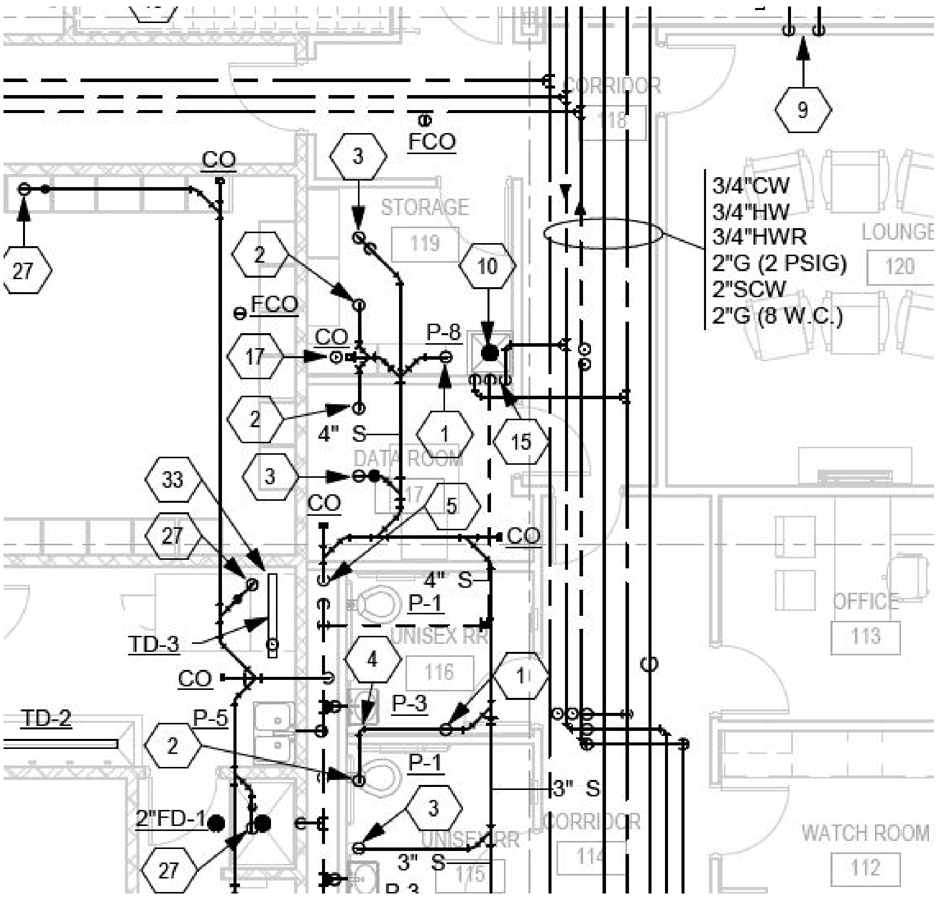

Figure D.3. Plumbing over data room, for phase 3 case

Appendix E: Phase 3 Rubric

Table E.1
Rubric for phase 3

	Good (2 points)	Fair (1 points)	Poor (0 points)
Construct-ability (x2) (CS)	Solved all or most major issues	Only partially addressed major issues or created new issues	Did not address any major issues and created new issues
Scheduling & budget (SB)	Solution can be implemented with no construction delays or extra costs	Solution can be implemented with some delay and/or some extra costs	Solution will take too long and/or costly to be executed
Complexity (CX)	Solution can be implemented with minor revisions in plans	Solution will affect several designers or creates major design revisions	Solution affects several designers and creates the demand for discussions
Aesthetics and Usability (AU)	Solution improves building aesthetics and/or usability	Solution did not alter aesthetics or usability of building	Solution diminishes building aesthetics and/or usability

Appendix F: Interview Questions for Validation of Guidelines

Questions to be asked for faculty members of the design and construction management departments with industry and teaching experience. The researcher will share main findings with faculty before the meeting.

a Do you think these findings reflect accurately your industry experience?

b Do you think these findings reflect accurately your instructor experience?

c What do you think are the reasons for differences/similarities in channels?

d What do you think are the reasons for differences/similarities in from students and professionals?

e The researcher has prepared these guidelines [show printed guidelines] based on the findings to help students and young professionals deal with channel constraints for design issues. Do you have any comments or suggestions?

f Is there anything else you would like to add?

Appendix G: Institutional Review Board Approval

IRB approvals (original protocol and amendments) for all research duration.

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HUMAN RESEARCH PROTECTION PROGRAM
INSTITUTIONAL REVIEW BOARDS

To:	MARK SHAURETTE KNOY 429
From:	JEANNIE DICLEMENTI, Chair Social Science IRB
Date:	04/09/2015
Committee Action:	**Approval**
IRB Action Date	04/08/2015
IRB Protocol #	1503015884
Study Title	A mixed methods study on choice of media influence on construction industry communication
Expiration Date	04/07/2016

Following review by the Institutional Review Board (IRB), the above-referenced protocol has been approved. This approval permits you to recruit subjects up to the number indicated on the application form and to conduct the research as it is approved. The IRB-stamped and dated consent, assent, and/or information form(s) approved for this protocol are enclosed. Please make copies from these document(s) both for subjects to sign should they choose to enroll in your study and for subjects to keep for their records. Information forms should not be signed. Researchers should keep all consent/assent forms for a period no less than three (3) years following closure of the protocol.

Revisions/Amendments: If you wish to change any aspect of this study, please submit the requested changes to the IRB using the appropriate form. IRB approval must be obtained before implementing any changes unless the change is to remove an immediate hazard to subjects in which case the IRB should be immediately informed following the change.

Continuing Review: It is the Principal Investigator's responsibility to obtain continuing review and approval for this protocol prior to the expiration date noted above. Please allow sufficient time for continued review and approval. No research activity of any sort may continue beyond the expiration date. Failure to receive approval for continuation before the expiration date will result in the approval's expiration on the expiration date. Data collected following the expiration date is unapproved research and cannot be used for research purposes including reporting or publishing as research data.

Unanticipated Problems/Adverse Events: Researchers must report unanticipated problems and/or adverse events to the IRB. If the problem/adverse event is serious, or is expected but occurs with unexpected severity or frequency, or the problem/even is unanticipated, it must be reported to the IRB within 48 hours of learning of the event and a written report submitted within five (5) business days. All other problems/events should be reported at the time of Continuing Review.

We wish you good luck with your work. Please retain copy of this letter for your records.

Ernest C. Young Hall, 10th Floor - 155 S. Grant St. - West Lafayette, IN 47907-2114 - (765) 494-5942 - Fax: (765) 494-9911

Figure G.1. IRB approval April 09^{th}, 2015

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HUMAN RESEARCH PROTECTION PROGRAM
INSTITUTIONAL REVIEW BOARDS

To:	MARK SHAURETTE KNOY 429
From:	JEANNIE DICLEMENTI, Chair Social Science IRB
Date:	04/21/2015
Committee Action:	**Amendment to Approved Protocol**
IRB Action Date	04/17/2015
IRB Protocol #	1503015884
Study Title	A mixed methods study on choice of media influence on construction industry communication
Expiration Date	04/07/2016

Following review by the Institutional Review Board (IRB), the above-referenced protocol has been approved. This approval permits you to recruit subjects up to the number indicated on the application form and to conduct the research as it is approved. The IRB-stamped and dated consent, assent, and/or information form(s) approved for this protocol are enclosed. Please make copies from these document(s) both for subjects to sign should they choose to enroll in your study and for subjects to keep for their records. Information forms should not be signed. Researchers should keep all consent/assent forms for a period no less than three (3) years following closure of the protocol.

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Continuing Review: It is the Principal Investigator's responsibility to obtain continuing review and approval for this protocol prior to the expiration date noted above. Please allow sufficient time for continued review and approval. No research activity of any sort may continue beyond the expiration date. Failure to receive approval for continuation before the expiration date will result in the approval's expiration on the expiration date. Data collected following the expiration date is unapproved research and cannot be used for research purposes including reporting or publishing as research data.

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We wish you good luck with your work. Please retain copy of this letter for your records.

Ernest C. Young Hall, 10th Floor - 155 S. Grant St. - West Lafayette, IN 47907-2114 - (765) 494-5942 - Fax: (765) 494-9911

Figure G.2. IRB amendment approval April 12^{th}, 2015

PURDUE UNIVERSITY

HUMAN RESEARCH PROTECTION PROGRAM
INSTITUTIONAL REVIEW BOARDS

To:	MARK SHAURETTE KNOY 429
From:	JEANNIE DICLEMENTI, Chair Social Science IRB
Date:	09/03/2015
Committee Action:	**Amendment to Approved Protocol**
IRB Action Date	09/03/2015
IRB Protocol #	1503015884
Study Title	A mixed methods study on choice of media influence on construction industry communication
Expiration Date	04/07/2016

Following review by the Institutional Review Board (IRB), the above-referenced protocol has been approved. This approval permits you to recruit subjects up to the number indicated on the application form and to conduct the research as it is approved. The IRB-stamped and dated consent, assent, and/or information form(s) approved for this protocol are enclosed. Please make copies from these document(s) both for subjects to sign should they choose to enroll in your study and for subjects to keep for their records. Information forms should not be signed. Researchers should keep all consent/assent forms for a period no less than three (3) years following closure of the protocol.

Revisions/Amendments: If you wish to change any aspect of this study, please submit the requested changes to the IRB using the appropriate form. IRB approval must be obtained before implementing any changes unless the change is to remove an immediate hazard to subjects in which case the IRB should be immediately informed following the change.

Continuing Review: It is the Principal Investigator's responsibility to obtain continuing review and approval for this protocol prior to the expiration date noted above. Please allow sufficient time for continued review and approval. No research activity of any sort may continue beyond the expiration date. Failure to receive approval for continuation before the expiration date will result in the approval's expiration on the expiration date. Data collected following the expiration date is unapproved research and cannot be used for research purposes including reporting or publishing as research data.

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We wish you good luck with your work. Please retain copy of this letter for your records.

Ernest C. Young Hall, 10th Floor - 155 S. Grant St. - West Lafayette, IN 47907-2114 - (765) 494-5942 - Fax: (765) 494-9911

Figure G.3. IRB amendment approval September 03th, 2015

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HUMAN RESEARCH PROTECTION PROGRAM
INSTITUTIONAL REVIEW BOARDS

To:	MARK SHAURETTE KNOY 429
From:	JEANNIE DICLEMENTI, Chair Social Science IRB
Date:	09/17/2015
Committee Action:	**Amendment to Approved Protocol**
IRB Action Date	09/16/2015
IRB Protocol #	1503015884
Study Title	A mixed methods study on choice of media influence on construction industry communication
Expiration Date	04/07/2016

Following review by the Institutional Review Board (IRB), the above-referenced protocol has been approved. This approval permits you to recruit subjects up to the number indicated on the application form and to conduct the research as it is approved. The IRB-stamped and dated consent, assent, and/or information form(s) approved for this protocol are enclosed. Please make copies from these document(s) both for subjects to sign should they choose to enroll in your study and for subjects to keep for their records. Information forms should not be signed. Researchers should keep all consent/assent forms for a period no less than three (3) years following closure of the protocol.

Revisions/Amendments: If you wish to change any aspect of this study, please submit the requested changes to the IRB using the appropriate form. IRB approval must be obtained before implementing any changes unless the change is to remove an immediate hazard to subjects in which case the IRB should be immediately informed following the change.

Continuing Review: It is the Principal Investigator's responsibility to obtain continuing review and approval for this protocol prior to the expiration date noted above. Please allow sufficient time for continued review and approval. No research activity of any sort may continue beyond the expiration date. Failure to receive approval for continuation before the expiration date will result in the approval's expiration on the expiration date. Data collected following the expiration date is unapproved research and cannot be used for research purposes including reporting or publishing as research data.

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We wish you good luck with your work. Please retain copy of this letter for your records.

Ernest C. Young Hall, 10th Floor - 155 S. Grant St. - West Lafayette, IN 47907-2114 - (765) 494-5942 - Fax: (765) 494-9911

Figure G.4. IRB amendment approval September 16^{th}, 2015

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HUMAN RESEARCH PROTECTION PROGRAM
INSTITUTIONAL REVIEW BOARDS

To:	SHAURETTE, MARK E
From:	DICLEMENTI, JEANNIE D, Chair Social Science IRB
Date:	01 / 11 / 2016
Committee Action:	Amended Exemption Granted
Action Date:	01 / 11 / 2016
Protocol Number:	1503015884
Study Title:	A mixed methods study on choice of media influence on construction industry communication

The Institutional Review Board (IRB) has reviewed the above-referenced amended project and has determined that it remains exempt. If you wish to make changes to this study, please refer to our guidance"**Minor Changes Not Requiring Review**" located on our website at http://www.irb/purdue.edu/policies.php. For changes requiring IRB review, please **Create a New Amendment** through the CoeusLite Online Submission System.Please contact our office if you have any questions.

Below is a list of best practices that we request you use when conducting your research. The list contains both general items as well as those specific to the different exemption categories.

General

- To recruit from Purdue University classrooms, the instructor and all others associated with conduct of the course (e.g., teaching assistants) must not be present during announcement of the research opportunity or any recruitment activity. This may be accomplished by announcing, in advance, that class will either start later than usual or end earlier than usual so this activity may occur. It should be emphasized that attendance at the announcement and recruitment are voluntary and the student's attendance and enrollment decision will not be shared with those administering the course.
- If students earn extra credit towards their course grade through participation in a research project conducted by someone other than the course instructor(s), such as in the example above, the students participation should only be shared with the course instructor(s) at the end of the semester. Additionally, instructors who allow extra credit to be earned through participation in research must also provide an opportunity for students to earn comparable extra credit through a non-research activity requiring an amount of time and effort comparable to the research option.
- When conducting human subjects research at a non-Purdue college/university, investigators are urged to contact that institution's IRB to determine requirements for conducting research at that institution.
- When human subjects research will be conducted in schools or places of business, investigators must obtain written permission from an appropriate authority within the organization. If the written permission was not submitted with the study application at the time of IRB review (e.g., the school would not issue the letter without proof of IRB approval, etc.), the investigator must submit

Figure G.5. IRB amendment approval January 11^{th}, 2015

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HUMAN RESEARCH PROTECTION PROGRAM
INSTITUTIONAL REVIEW BOARDS

To:	MARK SHAURETTE KNOY 429
From:	JEANNIE DICLEMENTI, Chair Social Science IRB
Date:	02/19/2016
Committee Action:	**Amendment to Approved Protocol**
IRB Action Date	02/19/2016
IRB Protocol #	1503015884
Study Title	A mixed methods study on choice of media influence on construction industry communication
Expiration Date	04/07/2016

Following review by the Institutional Review Board (IRB), the above-referenced protocol has been approved. This approval permits you to recruit subjects up to the number indicated on the application form and to conduct the research as it is approved. The IRB-dated consent, assent, and/or information form(s) approved for this protocol are in the Attachments of this protocol through CoeusLite. Please make copies from these document(s) both for subjects to sign should they choose to enroll in your study and for subjects to keep for their records. Information forms should not be signed. Researchers should keep all consent/assent forms for a period no less than three (3) years following closure of the protocol.

Revisions/Amendments: If you wish to change any aspect of this study, please submit the requested changes to the IRB through the CoeusLite Online Submission System. IRB approval must be obtained before implementing any changes unless the change is to remove an immediate hazard to subjects in which case the IRB should be immediately informed following the change.

Continuing Review: It is the Principal Investigator's responsibility to obtain continuing review and approval for this protocol prior to the expiration date noted above. Please allow sufficient time for continued review and approval. No research activity of any sort may continue beyond the expiration date. Failure to receive approval for continuation before the expiration date will result in the approval's expiration on the expiration date. Data collected following the expiration date is unapproved research and cannot be used for research purposes including reporting or publishing as research data.

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You are required to retain a copy of this letter for your records. We appreciate your commitment towards ensuring the ethical conduct of human subjects research and wish you luck with your study.

Ernest C. Young Hall, 10th Floor - 155 S. Grant St. - West Lafayette, IN 47907-2114 - (765) 494-5942 - Fax: (765) 494-9911

Figure G.6. IRB amendment approval February 19^{th}, 2015

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HUMAN RESEARCH PROTECTION PROGRAM
INSTITUTIONAL REVIEW BOARDS

To:	MARK SHAURETTE KNOY 429
From:	JEANNIE DICLEMENTI, Chair Social Science IRB
Date:	03/14/2016
Committee Action:	**Amendment to Approved Protocol**
IRB Action Date	03/14/2016
IRB Protocol #	1503015884
Study Title	A mixed methods study on choice of media influence on construction industry communication
Expiration Date	03/13/2017

Following review by the Institutional Review Board (IRB), the above-referenced protocol has been approved. This approval permits you to recruit subjects up to the number indicated on the application form and to conduct the research as it is approved. The IRB-dated consent, assent, and/or information form(s) approved for this protocol are in the Attachments of this protocol through CoeusLite. Please make copies from these document(s) both for subjects to sign should they choose to enroll in your study and for subjects to keep for their records. Information forms should not be signed. Researchers should keep all consent/assent forms for a period no less than three (3) years following closure of the protocol.

Revisions/Amendments: If you wish to change any aspect of this study, please submit the requested changes to the IRB through the CoeusLite Online Submission System. IRB approval must be obtained before implementing any changes unless the change is to remove an immediate hazard to subjects in which case the IRB should be immediately informed following the change.

Continuing Review: It is the Principal Investigator's responsibility to obtain continuing review and approval for this protocol prior to the expiration date noted above. Please allow sufficient time for continued review and approval. No research activity of any sort may continue beyond the expiration date. Failure to receive approval for continuation before the expiration date will result in the approval's expiration on the expiration date. Data collected following the expiration date is unapproved research and cannot be used for research purposes including reporting or publishing as research data.

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You are required to retain a copy of this letter for your records. We appreciate your commitment towards ensuring the ethical conduct of human subjects research and wish you luck with your study.

Ernest C. Young Hall, 10th Floor - 155 S. Grant St. - West Lafayette, IN 47907-2114 - (765) 494-5942 - Fax: (765) 494-9911

Figure G.7. IRB amendment approval March 14^{th}, 2016

Appendix H: Communications for use of phase 3 plans

Communications with Kokomo Municipality in order to obtain authorization to use Kokomo Fire Station #2 Plans in Dissertation:

RE: Request for help for dissertation - use of Bid documents for Kokomo Fire Station #2

Erin E. Miller <[redacted]@cityofkokomo.org>

Thu 3/3/2016 2:09 PM

To:de Cresce El Debs, Luciana <ldecresc@purdue.edu>;

Good afternoon,

In reference to your email about using the City of Kokomo's construction drawing for Fire Station No. 2, the City of Kokomo grants permission for the use of these documents for your research. Good luck on your endeavor !

Thank you,

From: de Cresce El Debs, Luciana [mailto:ldecresc@purdue.edu]
Sent: Tuesday, March 01, 2016 2:17 PM
To: Erin E. Miller <[redacted]@cityofkokomo.org>
Subject: Request for help for dissertation - use of Bid documents for Kokomo Fire Station #2
Importance: High

Dear Ms Miller,

I am a PhD students at Purdue University - more specifically at the School Construction Management Technology.

I have a set of construction drawings used for bids (July 9, 2010 Bid Documents) for the Kokomo Fire Station #2. I am conducting research on team problem solving between designers and construction management and would like to know if I could use this set within a case study that I have developed. This case involves creating a scenario for pairs of students and professionals of a construction problem. For this, they will have to use the plans to develop an alternate solution. The case is purely fictitious and in no way is related to the construction of the fire station. However using these documents will give a 'real world' feeling to the study.

I can certainly give more information as well as to how they will be used and anything else you might want to know about the research.

Please find attached the first page of the set, in case you want to verify which set I'm talking about.

Please let me know your thoughts.

My advisor at Purdue is Dr. Mark Shaurette (mshauret@purdue.edu) and you may email or call him ([redacted]) as well.

Thank you so much!

Regards,

Luciana de C. El Debs, M.Sc.,
PhD Candidate, School of Construction Management
Purdue Polytechnic Institute
Purdue University

[UrlBlockedError.aspx]www.linkedin.com/in/lucianadebs
Mailto: *ldecresc@purdue.edu*

Communications with Axis Architecture in order to obtain authorization to show Kokomo Fire Station #2 Plans in Dissertation:

Re: Kokomo Fire Station 2 for dissertation study

de Cresce El Debs, Luciana

Mon 3/28/2016 10:20 AM

To:Chris Hagan <[redacted]@axisarch.com>;

1 attachment

EmailFromKokomo.pdf;

Dear Mr. Hagan,

I have already pdf set of the documents because they were from a public building bid set. I have approval from the city of Kokomo to use them in my research (attached email chain). However because you were the architect in charge, I would like confirmation from you about using the images I've mentioned to you in the dissertation written document.

I do not need the cad drawings or any other documents.

Regards,

Luciana de C. El Debs, M.Sc.,
PhD Candidate, School of Construction Management
Purdue Polytechnic Institute
Purdue University

[www.linkedin.com/in/lucianadebs]www.linkedin.com/in/lucianadebs
Mailto: *ldecresc@purdue.edu*

From: Chris Hagan <[redacted]@axisarch.com>
Sent: Monday, March 28, 2016 9:35 AM
To: de Cresce El Debs, Luciana
Subject: RE: Kokomo Fire Station 2 for dissertation study

Luciana –

I don't have a problem with you using that particular drawing sheet and view for your dissertation. If you need copies of the drawings or PDF's I would need written confirmation from the city.

Best –

Chris

CHRIS HAGAN, AIA, LEED AP
ASSOCIATE PRINCIPAL

AXIS ARCHITECTURE + INTERIORS

618 EAST MARKET STREET
INDIANAPOLIS, INDIANA 46202
317.264.8162
WWW.AXISARCH.COM

From: de Cresce El Debs, Luciana [mailto:ldecresc@purdue.edu]
Sent: Thursday, March 24, 2016 11:24 AM
To: Chris Hagan <[redacted]@axisarch.com>
Subject: Kokomo Fire Station 2 for dissertation study

Dear Mr. Hagan,

I am currently a PhD student in the Construction Management Technology at Purdue University. My area of study is communication between site/construction personnel and design personnel, with special emphasis on design issues. I have talked to Kokomo major's office and they have authorized me to use the bid plans (set of July 9th, 2010) for the Kokomo fire station #2 in my study.

However, I would like to know from you if I could show the G002 plan (safety plan), and a close up of room 117 in P201 in my dissertation.

I have developed a case, which does not accurately represent any real issue, but is based on my previous experience and interviews with professionals (design and construction), around the pipes over room 117 (equipment room).

Please let me know if this is possible, or if you have any questions or concerns about this.

Regards,

Luciana de C. El Debs, M.Sc.,
PhD Candidate, School of Construction Management
Purdue Polytechnic Institute
Purdue University

[www.linkedin.com/in/lucianadebs]www.linkedin.com/in/lucianadebs
Mailto: *ldecresc@purdue.edu*

VITA

VITA

LUCIANA DEBS

EDUCATION

2016, **PhD in Technology**, concentration in Construction Management Technology, Purdue University West Lafayette, IN

2013, **MS in Real Estate Development: Technology and Planning**, Technological Research Institute of Sao Paulo (IPT SP) Sao Paulo, Brazil

2005, **BS in Architecture**, University of Sao Paulo (USP) Sao Paulo, Brazil

RESEARCH INTERESTS

- Design and construction personnel interaction;
- Management of design information in construction industry;
- Information flow in construction industry;
- Problem solving in multidisciplinary environments.

JOURNAL PUBLICATIONS

de Cresce El Debs, L. & Kelley, T. (2015). Gathering design references from nature. *The Technology and Engineering Teacher.* Sep2015, Vol. 75 Issue 1, p10-14. 5p

Debs, L. C. & Ferreira, S. L. (2014). Guidelines for a design process for facades with precast concrete panels in a BIM environment. In: *Ambiente Construido.* 14:2, p. 41-60.

CONFERENCE PROCEEDINGS

Gray, C., de Cresce El Debs, L., Exter, M. & Krause, T. (2016). Instructional Strategies for Incorporating Empathy in Transdisciplinary Technology Education. *ASEE National Conference Proceedings.* June 26-29, 2015, New Orleans, LA.

de Cresce El Debs, L., Shaurette, M., & Benhart, B. (2016). Professional Certifications in Construction Industry: A Comparative View from Students and Companies. *ASC Annucal Conference Proceedings* April 13-16, 2016, Provo, UT.

de Cresce El Debs, L., Dionne, R., Exter, M. & Shaurette, M. (2015). Problem solving in a multidisciplinary environment: observations from a newly developed program. *ASEE National Conference Proceedings.* June 14-17, 2015, Seattle, WA.

Debs, L. C. & Ferreira, S. L. (2013). Specifications for a BIM computational tool for conceiving faade design with precast panels. In 6o Encontro de Tecnologia de Informacao e Comunicacao na Construcao. Campinas. *Anais. . . .* PPGAU/EESC/USP. p. 411-422.

EL Debs, L. C. & Ferreira, S. L. (2013). Analysis of the potential of using BIM applications for designs with precast elements. In: 3o. Encontro Nacional Pesquisa-Projeto-Producao em Pre-Moldados 2013. *Anais do 3o. Encontro Nacional Pesquisa-Projeto-Producao em Pre-moldados.* Sao Carlos: EESC-USP.

Debs, L. C., Ferreira, S. L., & Villares, A. B. A. (2012). Application of Automated Code Checking in Brazilian Building Regulations. In: CIB W078, 2012, Beirut. *Proceedings. . .* Beirut: Lebanese American University. p. 52-61.

OTHER PUBLICATIONS

Debs, L. C. & Ferreira, S. L. (2013) Analysis of the potential of using BIM tools for designs with precast elements. In: *Concreto & Construcoes.* N. 72. October-December 2013. p. 53-58. (not peer revised)

Debs, L. C. (2013). *Proposal of a BIM computational tool to assist the design of architectural precast concrete panel facades.* Dissertation presented for obtaining the degree of Master in Habitat. IPT-SP, 2013. Sao Paulo. 200p.

PRESENTATIONS

de Cresce El Debs, & Shaurette, M. (2016), Conceptualizing a New Undergraduate Degree: Design-Construction Integration. Associated Schools of Construction Annual Conference 2016. Provo, UT (poster presentation).

de Cresce El Debs, L., Miller, K, & Exter, M. (2015), A Students Perspective on Different Teaching Methods. Association for Education Communications & Technologies Annual Conference 2015. Indianapolis, IN (roundtable presentation).

de Cresce El Debs, L., & Brophy, S. (2015). Assessing communication skills associated with spatial information. NCEER Conference: Integrating Cognitive Science with Innovative Teaching in STEM Disciplines. September 18-19, 2015, Evanston, IL (poster presentation).

Debs, L. C. & Ferreira, S. L. (2012). Proposal for a BIM computational tool for elaborating faade design with precast pieces. In: Encontro Nacional de Tecnologia do Ambiente Construido 2012, Juiz de Fora, Brazil (poster presentation).