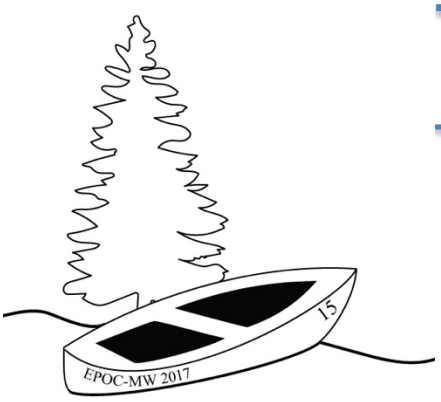

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Measuring Shared Understanding: Developing Research Methods for Empirical Research on Interdisciplinary Engineering Team Practices

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MEASURING SHARED UNDERSTANDING: DEVELOPING RESEARCH METHODS FOR EMPIRICAL RESEARCH ON INTERDISCIPLINARY ENGINEERING TEAM PRACTICES

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ABSTRACT

This paper shares early findings from a new study that seeks to explore a novel use of Photo Elicitation techniques in combination with Ethnography to assess the amount of Shared Understanding in multidisciplinary teams consisting of architects, engineers and construction managers working together on a building design project. The contribution herein is in exploring a new methodological strategy that will enable scholars to study collaborative design and assess the effectiveness of emerging design and data visualization strategies that architects, engineers and builders employ when sharing out technical analysis (translating) and engaging in distributed decision making (synthesis). To that end, we review current research methods used across a variety of disciplines such as cognitive psychology, human computer interaction,computer science, health care and sociology to measure or assess Shared Understanding, also known as Shared Team Mental Models. We then review the use of Photo Elicitation and its potential for engineering communication and design studies where the "photos" are visualizations that team members develop in order to communicate analysis or design. We then define the novel approach of using Photo Elicitation in combination with Ethnography and share a pilot of this approach conducted with students in an interdisciplinary project-based class. Over a 10-week class, we studied the interactions between students from architecture, building science and construction management and the visualizations these students created and used to learn and develop integrated design skills. In this paper we share what we have learned from this first pilot that includes the challenges of eliciting specifics related to Shared Understanding or Shared Mental Models in interviews. We also include methodological innovations such as action research, which we plan to try next to address the limitations we have experienced so far.

KEYWORDS: Research Methodology, Shared Understanding, Shared Team Mental Models, Integrated Design, Collaboration, Engineering Communication, Photo Elicitation, Ethnography

INTRODUCTION

As the industry moves towards collaborative delivery methods in support of higher performance building outcomes, today's architects and engineers grapple with more data, more people, and less time (Reed and 7 group 2009; AIA National and AIA California Council 2007; Aksamija

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2013; Cheng 2015). Design theory suggests collaborative problem solving leads to innovation, but multidisciplinary projects often fall short of this potential because experts from different fields lack the communication and collaboration skills they need to translate their work across disciplinary boundaries. Joint problem solving requires teams to address differences in values, requirements, and constraints, as happens when a structural engineer collaborates with an architect. Few engineers are trained explicitly in these skills, yet engineering problems from hardware to infrastructure, from nanotechnology to skyscrapers require engineers to work with teams of experts from different fields.

In this paper, we present a study of student teams with a focus on research methods for studying collaboration in these settings. Our research to date suggests a paradox: more detailed visualizations make it easier for interdisciplinary teams to identify and agree upon problems while making it harder for them to generate solutions (Dossick and Neff 2011, 2014). The answer to this paradox, we think, is in the communication strategies that engineers use with other professionals. In order to study the effectiveness of communication strategies, scholars need methods to assess the effectiveness of design visualizations and team dialogue. In this paper, we focus on the concept of Shared Understanding—shared knowledge, mental models and disciplinary insights that provide a basis for design decision-making.

Design Visualizations range from informal sketches to formal design plans and specifications. They include visual representations from engineering analysis software that may include strategies such as heat maps, gantt charts, bar graphs, or spreadsheets. These visualizations serve several functions in a multidisciplinary team: they are cognitive resources for their creators; they are sites for conversation; and they play an important role in documenting design decisions (Whyte et al. 2008; Ewenstein and Whyte 2009; Neff, Fiore-Silfvast, and Dossick 2010; Suwa, Gero, and Purcell 2000). In the latter two of these roles, design visualizations are part of the socio-material infrastructures that cultivate shared understanding across the team.

Shared Understanding supports integrated design processes where problems and solutions emerge from team member interactions with design visualizations (Whyte et al. 2008; Suwa, Gero, and Purcell 2000). Team members have deep knowledge in their expertise, but they share a part of their knowledge in explaining design ideas, disciplinary constraints, and technical analysis to collaborate, find solutions, and make decisions (Kleinsmann and Valkenburg 2008). described Shared Understanding with a simple example of an electrical engineer having a conflict with an ergonomist regarding the design of a circuit board. The electrical engineer used drawings and mathematical formulas to try to explain the maximum amount of space he could use for the circuit board, while the ergonomist provided human body movement theories to explain the same issue. Neither understood the deep disciplinary reasons provided by the other party, but they had Shared Understanding of the problem: the maximum amount of space needed for the circuit. Prior studies suggest that Shared Understanding is highly desirable for interdisciplinary teams in that it has a positive effect on team performance and team member satisfaction (Langan-Fox, Code, and Langfield-Smith 2000), as well as innovation (Kleinsmannm, Buijs, and Valkenburg 2010), and reduces re-work (Kleinsmann and Valkenburg 2008).

In order to assess the impact that design visualizations have on Shared Understanding, scholars need a method to assess Shared understanding across multidisciplinary teams. Towards this end, we present an effort to use Photo Elicitation techniques paired with ethnographic methods to assess Shared Understanding in integrated AEC teams and understand the role

visualizations play in developing Shared Understanding around potential design options. We first present a review of literature on methods of measuring Shared Understanding and applying Photo Elicitation methods. We then present a pilot study where we implemented these methods with architecture, building science and construction management student teams as they worked through a 10-week project-based class on integrated design. We present what worked in the pilot, what challenges and limitations we discovered, as well as a proposal for further methodological development.

LITERATURE REVIEW

In this review of literature, we first review published Shared Team Mental Model methods for measuring Shared Understanding. Next, we introduce Photo Elicitation methods and identify aspects of this method that lends itself to the study of Shared Understanding in AEC teams.

SHARED UNDERSTANDING AND MENTAL MODEL METHODS

Measuring Shared Understanding requires an understanding about the knowledge shared in the team. Johnson and O'Connor (2008) classifies knowledge into two types: team knowledge and task knowledge. Team knowledge is generally related to team processes and characteristics. Five factors affect team knowledge: 1) teammate knowledge, 2) team skills, 3) team attitudes, 4) team dynamics, and 5) team environment. The first factor entails knowledge about team members and their tasks. Team skill consists of the abilities associated with successful team performance. Team attitude is defined as teammate beliefs and values that influence team members' decision-making. Team dynamics are the combination of team coordination and cohesion processes. Finally, team environment is related to all external factors (e.g. technical, organizational) affecting team knowledge. In contrast to the five factors of team knowledge, task knowledge is the knowledge related to only a specific task (Johnson and O'Connor 2008).

Team members represent their knowledge about their environment in form of mental models (Langan-Fox, Code, and Langfield-Smith 2000). Mental models are organized knowledge structures that allow for each team member to interact with their environment, and help to predict and explain environmental behaviors or understand relationships between different components (Rouse and Morris 1985). Cannon-Bowers et al. (1993) argue that there are more than one type of mental model that can be shared in team. Mathieu et al. (2000)'s typology describes four mental model types associated with the types of knowledge described in the previous section: 1) Technology/equipment mental models, 2) Job/task mental models, 3) team interaction mental models, and 4) team mental models. Researchers have developed different methods for measuring Shared Team Mental Models (STMM), which mostly focuses on team and task mental models. STMM methods select and measure different concepts based on the research topic and the field of team member expertise. Then, using different elicitation methods, researchers construct the mental model structure of individuals based on an individual's understanding of concept relationships. At the end, these structures are aggregated to create a team mental model. The most frequently used STMM elicitation methods are as follows.

Cognitive Interviewing: This method can be conducted in three formats. The first format consists of team members engaged in an open conversation, the second format is question-answer where team members provide casual explanations about their domain of expertise. The last format is the inferential flow analysis where the participants are asked to explain the relationship between the concepts in their expertise. Langan-Fox et al. (2000) recommend use of

this method with caution as this method is heavily dependent on the researcher's interpretation of the participants' answers, and is inadequate for capturing the complex knowledge organizations.

Concept Mapping: In this method, concepts are represented as a box and the relationship between the concepts is represented by a line. Team members are asked to sort out the concepts based on their relationships. The researcher or participants cans select the concepts. Johnson and O'Connor (2008) define a standardized method called Analysis-Constructed Shared Mental Model for mapping the structure. One of the main advantages of this method is that it directly captures knowledge structures; however it requires team members to be trained in the method (Langan-Fox, Code, and Langfield-Smith 2000). Mohammed et al. (2000) also point out at the influence of the researcher on determining the structure.

Pairwise rating: In this method, the researcher selects concepts and participants rate the relatedness or similarity of the concepts on a Likert-type scale. A computer-based pairwise rating method can also save analysis time. Besides the cognitive content and structure, this method can capture the sequence of task-related activities (Mohammed, Klimoski, and Rentsch 2000).

Card Sorting: In this method concepts can be selected by the researcher, or the participant. The participant is then asked to sort the cards into piles based on their relationship, and explain the reason why they have arranged the concepts in such a way. This method is quick and easy to conduct (Langan-Fox, Code, and Langfield-Smith 2000). This method can be influenced by the researcher while determining the cognitive content and structure (Mohammed, Klimoski, and Rentsch 2000).

Qualitative method: In this method, researchers observe, video record, and code team interactions to collect data at the team level. Participants determine the concepts in their own terminologies. Coding might be time consuming, and the researcher can influence the structure analysis (Mohammed, Klimoski, and Rentsch 2000).

Specific to studying AEC teams, Casakin and Badke-Schaub (2015) studied two groups of designers, architects and engineers to explore the differences of design activities across multiple disciplines. In this study, a Qualitative method was used to examine the mental models of the participants and teams. The meetings were videotaped and coded according to three mental models categories of task, process, and team cohesion. Discussions regarding problem definition, new solution/idea, solution analysis/evaluation, explanation and solution decision were categorized under task mental model activities. Planning, procedure and reflection discussions were categorized under process mental model activities, and finally appreciation, confirmation, rejection and help discussions were categorized under team cohesion mental model activities. Engineers had more task activities and less processes activities in comparison with architects. The results indicate that while engineers spend most of their communication time and effort on tasks, architects are mostly focused on team coordination to gain better understanding of the process. This study examined differences between mental models exposed by team interactions, but did not elicite team mental model structures.

PHOTO ELICITATION - APPLICATIONS

While ethnography has been extensively used to study team interactions in architecture and engineering design contexts, Photo elicitation techniques are rarely used in engineering contexts to date. This section reports on the methodological development and pilot use of modified photo elicitation methods to capture team members' multiple perspectives on collaboration and to assess Shared Understanding around shared design problems. Photo elicitation uses visual prompts "in order to elicit reactions and information...which might otherwise never become apparent" (Schwartz 1989, 122). Photographs help researchers understand subtle differences in

"common or mundane expressions of values" (Schwartz 1989). Photo elicitation privileges "the respondent as expert, inhabiting the context of study, and developing a rich narrative response, and further facilitates an exploratory investigation of situated values" (Le Dantec, Poole, and Wyche 2009). The use of photo elicitation in research has grown in recent years to tacit knowledge and non-traditional knowledge, such as children's thinking in spontaneous and intuitive ways in support of city planning efforts (Tötzer, Sedlacek, and Knoflacher 2011). The technique has been applied to link behaviors with engineering needs, such as the linking of personal hygiene to water resources (Badowski et al. 2011) and as interview prompts in understanding organizational change (Ray and Smith 2012). The method also has value for gaining insight into the personal interpretation of the built environment (Fusco et al. 2012). However, there has been a dearth of applications of the photo elicitation technique in architectural and engineering design studies, yet architecture and engineering abound with visual information. Consequently, there are numerous opportunities to extend the use of photo elicitation to traditional drawing representations, simulations, and notably *BIM representations* (Kaminsky 2014).

For our study, we used design visualizations, such as models, drawings, energy simulations, and spreadsheets as "images" for interview prompts. We anticipated that these images would elicit multiple meanings and reactions as different team members view them and thus would support our researchers' investigation into particular moments in the collaboration process and the understanding that was shared and individual or disciplinary understanding. In this way we sought to observe the reactions, engagements, and co-constructions of meaning of collaboration around design visualizations that were not otherwise be apparent from observation alone, using visual materials to encourage participants through one-on-one interviews to "replay" what was happening in the moment. This methodical choice was motived by the literature in that scholars argue that the expressions around images offer a rich site for identifying values and goals about different kinds of data, tools, and models (Gaver, Dunne, and Pacenti 1999). Interview data using photo and visual elicitation can make explicit how participants think about their own team's communication (McDougall and Fels 2010).

The logic of paring photo elicitation methods with ethnography is to capture two sides of the coin: the social team interaction as well as the experts' internal dialogue and project understanding. With ethnographic methods that are well established, we sought to study the development of shared understanding observable from team interactions with design visualizations. With novel applications of photo elicitation, we sought to develop a means by which to assess the team's Shared Understanding by comparing what is voiced in team interactions with interviews that elicit internal dialog and professional reflection upon the same visualizations used in the team interaction.

METHOD DEVELOPMENT

This methodological development followed from two prior ethnographic studies (lasting 7 years in total) of professional AEC teams in design and construction projects as they used Building Information Modeling and Energy Modeling tools. We observed a limitation in the ethnographic work we undertook. We could observe Shared Understanding when it was stated explicitly by team members during meetings, but it was hard to assess how closely aligned the understand was across team members in many instances. In the ethnography we also observed the ramifications when shared understanding was not achieved, and misunderstandings lead to design decisions that did not take into consideration energy or constructability considerations. This ethnographic

work inspired the team to introduce Photo Elicitation methods to capture and measure the shared understanding from the team member's points of view.

SAMPLING, ORGANIZATION, & ANALYSIS OF VISUAL DATA.

We designed a process for sampling, collecting, analyzing, and interpreting the visual, observation, and interview data from teams for the study of collaborative understanding in interdisciplinary teams. Images were sampled from observed interactions of interdisciplinary collaboration. Researchers used photos of visualizations or copies of them to collect data on team members' practices, behaviors, and interactions, the BIM representations used, and other artifacts they use in their discussions. For interviews, we often asked participants to bring visualizations with them. These included screen captures, and printed documents that the researchers collected during observations of the teams, including BIM models, drawings, sketches and white board drawings. The criteria for inclusion into the sample is the use of a representation as part of a discussion among people from two or more different disciplines, such as systems engineers, architects, builders and specialty trade contractors, among others. These images will be sampled from studio and industry teams.

PHOTO ELICITATION IN PRACTICE: A PILOT

To develop novel methods of using Photo Elicitation techniques with design visualizations in combination with ethnography to assess Shared Understanding across multidisciplinary AEC teams, we conducted a pilot research project funded by a university innovation award.

INTEGRATED AEC STUDIO COURSE

Based on a long-standing collaboration among engineering, construction, and architecture faculty at [University Name], we created integrated studios that leverage BIM and building engineering and performance simulation technologies and integrated work practices to support interdisciplinary learning (Dossick & Pena 2010; Dossick et al. 2012). We collected empirical systematic data on interactions among the engineering, architecture and construction students in the project-learning course to understand how teams talk about, refer to, and communicate with and through visualizations in a controlled environment.

In this studio as well as in prior empirical research we have observed how disciplinary differences in culture, language, practices and norms currently divide engineers and architects. These differences often limit teams' abilities to interact and create the "shared understanding" that can lead to innovation. In this pilot, we developed Photo Elicitation interview methods and design team ethnographic strategies to study how shared BIM and energy modeling visualizations influenced the definition of problems and the creation of solutions between architecture, building science and construction management students; Through this pilot we sought to develop measurement strategies for how and when the process of interacting with BIM and energy modeling visualizations led to shared understanding; and verify how the method supports the study of how BIM and energy modeling visualizations influenced communication for innovative outcomes. These research methods include direct observations of studio student team interaction during "in class" team meetings, faculty coaching interactions, and studio reviews with external industry representatives. These observations were conducted in combination with interviews with individuals who were supposed to reflect on the interaction that the research team observed. In this way, we sought to develop a research method that both operationalizes shared understanding such that researchers can identify this phenomenon through

observation as well as triangulate that operationalization with first hand reflections by the actors to more fully assess the shared understanding that the team achieved.

PHOTO ELICITATION INTERVIEWS

During this phase of our research, we developed a structured Photo Elicitation interview tool that evolved throughout the course. Questions were removed or added based upon whether they were deemed effective for getting students to think through data visualization: in particular, recalling memories of working together around data.

The initial tool began with general questions on the student's roles and responsibilities on their team, including questions on how they felt about their team's level of collaboration. After some initial warm-up discussion, the Photo Elicitation section of the interview focused on gathering student stories about the data visualizations that they used on their team and asking whether these visualizations helped them make design decisions or find design opportunities with other team members. If the interview appeared to stall, such as when students were having trouble recalling stories about their interactions with team members, we would ask about specific events or moments that we had observed during our field work.

After several interviews with students, we also added two questions to our tool that appeared to elicit more in-depth and thoughtful responses from our participants. The first question asked what the student had learned from making the visualization and what had they taught others with the visualization. The second question asked students what they believed made an exceptional data visualization. These questions often elicited lengthy responses, greater story detail, and a desire to show further images and their stories.

Photo Elicitation Successes

Photo Elicitation was a successful research method in several ways. First, the method helped with student sensemaking (Weick 1995) around the challenges and solutions with producing and exchanging data and data visualizations. In particular, it helped students verbalize and make sense of how they could use the data that they produced and their visualizations to help with shared decision-making and generating shared understanding across their teams. Second, Photo Elicitation helped team members pinpoint specific visualization strategies that became a part of their team's visual toolkit, or shared language system, for making information meaningful across disciplines. The third success of the method was uncovering decision-making events that occurred outside of the observational field site.

As a means of sensemaking, Photo Elicitation helped students reflect on the challenges of making data visually meaningful for other team members. For example, as one cost estimator student noted about their estimation spreadsheets, "It's hard to make numbers exciting." Here, the student reflected that it was difficult to make information around building costs (i.e. "numbers") and their design implications meaningful to other team members.

Photo elicitation also helped with student sensemaking around how visualizations were only one part of a larger strategy for meaningful data exchange. These conversations focused on verbal strategies that helped team decision-making through shared understanding around project solutions and evoking confidence in those solutions. As one energy modeler noted:

> *"I'm supposedly an expert on this subject matter. And I'm having to kind of steer a group of people and convince them that what I know is correct and then I have all these fact and figures to back up what I'm telling them…I feel like there is a level of confidence that you have to…even if your stuff is all*

correct, but if you don't sell it in a way, and, you don't convince them that you don't know what you're talking about, it's really hard to get them on board."

Here, the modeler aptly notes that presenting data with a confident attitude—how you verbally "sell" your "facts and figures" and position yourself as an expert—was as important as producing data and visualizing data for generating team consensus on design problems and solutions.

Photo Elicitation was also significant in highlighting specific team and team member strategies for developing a cross-disciplinary shared visual language that provided shared understanding between different disciplines. For example, a construction facilitator noticed that their team's early decision to use specific icons (Figure 1) that represented specific design goals (e.g. sustainability, community engagement, constructability) generated a consistent language across the team that quickly and coherently demonstrated the design intent behind specific decisions. These logos were placed on visualizations shared amongst the team and in their final presentations. As the facilitator noted when showing me one of their site plans (Figure 2):

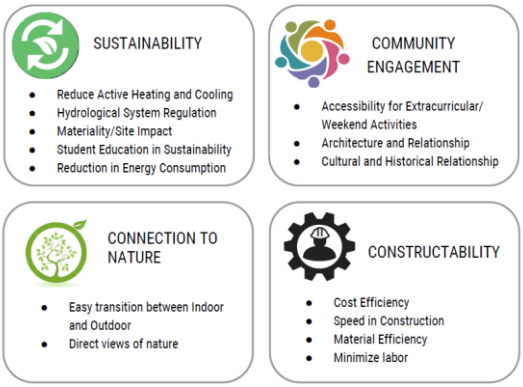


Figure 1: Team icons representing design goals.

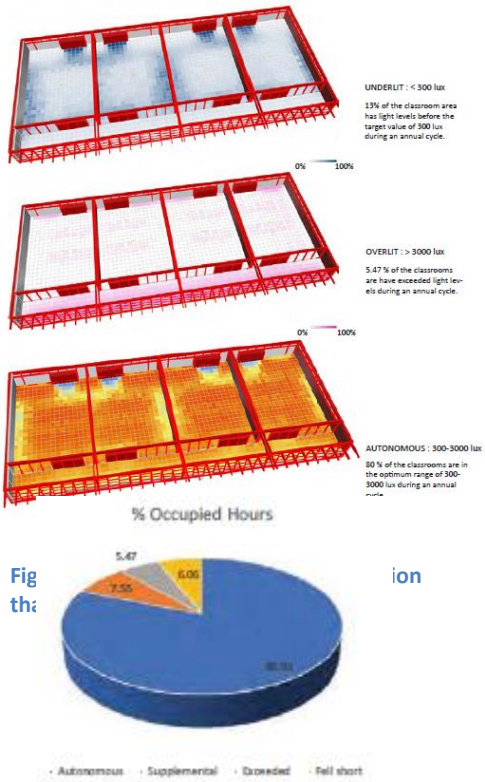
"…It's not a lot of text, but [we] used logos, icons and legends…. Because even if I didn't meet up with them, by seeing this presentation, I know what they are doing. I know where things go."

Figure 2: Icons used on site plan to show design intent of a rain garden.

Here, Photo Elicitation helped to uncover how a team's shared visual language emerged and how this language embedded specific project values and needs that their team members could understand without the need for further interaction or clarification.

In another example, Photo Elicitation helped uncover how an energy modeler's process for searching for an effective way to share daylighting information with architects evolved into a shared visual language with the architects. Through this interview, we are able to see how certain visualization types can be more effective for translating data into another stakeholder's "vocabulary."

In this case, the energy modeler had been grappling with how to help the architects understand the implications of her daylighting model visualizations. Despite the energy modeler's best attempts at explaining her model-generated images that depicted overlit, underlit,



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and autonomous daylighting conditions (see figure 3), the architects were still unclear as to what they represented and how it impacted their design: the image could not convey the meaning and value of the data for the architect in the way that it did for modeler.

The modeler then began to use simple pie charts to make the data more meaningful for the architects (see figure 4). Here, the pie chart simplified the data for the architects, showing them the level of lighting in relation to the hours in which the building would have problematic conditions. The pie chart helped the architects see that the percentage of occupied hours in which the building had lighting problems was rather small.

Figure 4: Pie chart showing same daylighting conditions

The energy modeler's adoption of architectural visual language became more advanced as she attempted to demonstrate a problem with glare on the south façade of their design and provide potential solutions to the problem. The modeler rendered the glare that would occur in a single room using an image that illustrated a first-person perspective of the space and the daylighting. This perspective visualization was similar to the types of visualizations that the architects regularly used to show the form, function, and experience of the designed space: to depict what one a person would experience standing in a room. Using these perspective views to illustrate the impact of glare in a room, the energy modeler provided the team with a visual language familiar to their discipline and was able to effectively show her team the impact of the glare and convinced the team to use louvers as a design solution (see Figure 5).

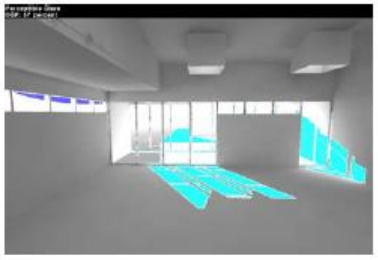

Figure 5: Render of glare from within model (top) and version using louvers (bottom).

A final way that photo elicitation provided insights was through uncovering interactions that occurred outside of the ethnographic field site of the studio classroom. In these interviews, participants were able to share stories in which their teams developed shared understanding around a specific problem and potential solution to design. For example, an energy modeler described their project's initial building design as having north facing classrooms with very little light getting into the building past a corridor on the southern side. The modeler described how she met with two architects outside of class time to show them her initial simulations with the daylighting model. After this event, the architects decided to add glass onto a southern corridor wall to provide daylight from the south into the northern classrooms.

Photo Elicitation Challenges

Despite these successes with using photo elicitation, there were some key challenges. The first key challenge was the linguistic and cultural differences between the interviewer and multiple interviewees. In our particular classroom context, many of our interview participants were international students. During interviews, it was often difficult to engage them in storytelling using the questions that we had developed in our tool. This was in stark contrast to students that were either from North America or had a high level of English language skills. Our participants that shared the language and cultural background of the interviewer easily engaged in retelling an event or situation when prompted to "tell a story about using a visualization" or asked if the visualization had helped their team "see design opportunities they would not have seen otherwise." In contrast, our international student responses tended to suggest either confusion about the language used in the questions or provided very short responses with little detail, even after multiple attempts at prompting a more detailed response. Different cultural contexts

produce different storytelling practices: our experience using photo elicitation in this particular research context highlighted these differences in cultural storytelling.

Another challenge was logistical in nature: finding the right moment to talk about a visualization and the right visualization to discuss. In this particular research case, we conducted interviews after the students' second cycle of design and after their third cycle of design. Due to the way team-based class days were schedules, many of the students were still not interacting in a more integrated manner with their teams at the conclusion of cycle 2. This meant that for many of our cycle 2 interviews, there were few stories of integrated interaction around data. Instead the students reported sharing visualizations over email with a focus on compiling images for the shared presentation file.

Furthermore, when students were asked to bring in visualizations they used as a team for the interview, they would often provide images that had not necessarily been used to make team decisions or that the team had seen outside of a final presentation to a panel of reviewers. In these cases, students often preferred to discuss what they had individually accomplished in the class as represented through the creation of the image. This was specifically the case for teams that had, at this point, shared visualizations primarily via email or on Google Drive. For example, after discussing what a construction facilitator learned from a cost estimator's visualization around pricing and materials, the facilitator replied that she had "rarely" met the cost estimators and learned this information "when they put it in the Google Drive, there is [sic] notifications for all of us and I read it through." In another example, after a lengthy discussion with another cost estimator around a specific visualization and her thoughts on its potential impact on their team's building design, the interviewer asked whether they had talked about this image with other team members. The estimator replied, "No it is just one we saw later…"

The third challenge is that the data generated from our photo elicitation techniques currently misses the importance of interactive gestures and performance in developing shared understanding on teams. While photo elicitation asks participants to verbalize their stories around their team interactions, and while participants would use small gestures (such as pointing) to show the interviewer where problems were located in a design, gestures that had been clearly seen during the ethnography were not recalled in their stories. We believe this is significant in that one of the current key findings of our ethnographic research is that team members perform design and construction solutions through using interactive and conversational forms of performance and gesture to represent ideas and engage with others during problem-solving.

Many gestures and performances were observed during fieldwork, including gestures made and exchanged with those in our photo elicitation interviews. However, gestures never made it into the stories told during photo elicitation beyond pointing to a location on a building to show the interviewer where problems and solutions occurred. The use of interactive gestures during storytelling recall for this specific population was nonexistent, leaving only part of the story of shared understanding untold. This last point in particular suggests that we need to develop a methodology to combine observation of team interaction with photo elicitation of individual's understanding of the issue at hand. We need to combine the observation of the performance in team interactions with individual reflections about Shared Understanding that was created by that performance.

Refining the Method

While the first phase of this study is limited in making broad generalizations about the use of photo elicitation with data visualizations and engineers, there are a few key ways we can refine the method for the second phase of research that other researchers may also consider when using

both methods. These key changes will help to meet the challenges of using this method in the field in terms of language and cultural differences, logistical challenges for conducting interviews and selecting visualizations for photo elicitation, and to better incorporate the use of gesture in interviews as a part of the shared understanding process. These suggestions all center on the need to fully integrate photo elicitation with ethnography as a form of action research. Through an outline of this methodological fusion for phase II of our research, we can help other researchers know what they need to consider if they wish to adapt these method.

First, one needs to consider the language and cultural differences around storytelling. For the integrated studio course, this is particularly challenging as our research participants come from multiple countries with different cultural expectations and methods of telling a story. For our own research team, we will be moving towards a more unstructured interview style that is more closely integrated with the observations made during the ethnography, rather than trying to stay within the constraints of a single interview tool that is designed for only one cultural and linguistic community. For researchers considering using this method in another culture besides their own, they should consider hiring a local researcher in their intended subject's community that best understands these language and cultural expectations.

Second, using photo elicitation means finding the right time to conduct interviews and the right images to use for interviews. As these cases show, there is a need to carefully consider when photo elicitation occurs during field work and the need to work with participants prior to the interview to select visualizations to work with. In our case, asking students to bring visualizations that they used on their project (even when requesting students bring images used for decision-making) did not always mean they were visualizations that they used for decision-making. We will explore ways of capturing images in ethnography as well as getting quick reflections from individuals on the team before they disband for the day.

To amend this, we again recommend not separating photo elicitation from the ethnography: but fusing the ethnography with photo elicitation. This transforms photo elicitation as a form of unstructured discussion around images that can occur immediately after interactions take place in the field or while interactions are in process. In practice, this would mean that the researcher needs to be fully integrated as a team member, engaging in dialogue with team members about project problems and solutions while gathering around and interacting with the imagery that the team is using to center their discussions and ideas. This both minimizes the time between an event and asking a participant to recall an event, while also allowing the researcher to engage in and personally reflect on their own development of shared understanding. Thus, a fully integrated ethnography and photo elicitation tool kit means that the researcher transforms from outside observer to inside participant observer. This action research oriented method means that the ethnographic practice becomes part of an active discussion happening in the field with participants: it becomes a part of the decision-making process. This also means that there is a higher chance of capturing the meaning of gestures and their potential influence in developing shared understanding on teams.

CONCLUSION

In this paper we explore research methods for studying teams of architects, engineers and construction managers as they design and construct our built environment. To this end, we share the research process with a description of the original research design of ethnography and photo elicitation. We present the successes and challenges of implementing this research design in a

project-based course, and present our plans for the next steps we can take to address the limitations of the original research design. For our study, as well as others who seek to apply photo elicitation to AEC contexts, we found that three issues need to be addressed in the research design. First, linguistic and cultural differences between the interviewer and multiple interviewees needs to be explored. Some cultures may support story telling, while other cultures may be less open to sharing personal thoughts and knowledge. Second, logistical considerations should be thought through as to how the researchers seek to capture the moments of interest. Third, we found it important to consider the limitations of photo elicitation methods for capturing the full picture of interaction around visualizations used in these teams. To address the second and third issues discovered in this first study, for our research questions around Shared Understanding, we found that we need to capture the Shared Understanding at the sight of team interaction, or make clear and explicit connections between the ethnographic observations of the "performance" around the visualization and the photo elicitation reflections from individual team members. We propose to use action research to make more explicit connections between the enthnography and the photo elicitation, where the researcher will play an active role in coaching communication in the project-based class, thereby having a vehicle to observe and then reflect with the students on how the visualizations worked to shared their analysis and create understanding across the team.

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