Cross-disciplinary AEC teamwork supported by re-representation

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Abstract

This paper presents a study of the relation between activities, media and communication channels, and re-representation in support of common ground building in cross-disciplinary, geographically distributed teams. We formalized the process of re-representation as a sequence of representations of the same concept using different media and communication channels. Our findings show that the re-representation technique fosters common ground building as it is used by global team members during multimodal and multimedia communicative events. Our hypotheses are: (1) a significant source of information behind decisions and request for actions that is embedded within the communicative events in which participants use both informal and formal representations and media to express their ideas. Capturing these information streams can facilitate common ground building and accelerate the execution of action requests. (2) Re-representations of concepts mediate and accelerate common ground building. (3) The use of intra or inter disciplinary re-representations correlate with high team performance, i.e., effective team process and high product quality. We used AEC Global Teamwork course offered in 2008-2009 as the testbed to study and validate our hypothesis.

*Keywords*: common ground, re-representation, global teamwork, communication channels, media

1 Introduction

“The globalization of economic activity is perhaps the defining trend of our time.” (O’Hara-Devereaux and Johansen, 1994) Increased connectivity provides unprecedented collaboration capabilities through diverse media and communication channels. Despite all the new information and collaboration technologies (ICT), distributed teams face challenges that face-to-face teams do not. Preparing the next generation of practitioners how to collaborate across disciplines, time, space, and culture is of increasing importance as distributed work becomes more prevalent and advantageous.

To achieve this objective we have launched in 1993 the architecture, engineering, construction (AEC) Global Teamwork course established by the PBL Lab at Stanford in collaboration with universities worldwide. (Fruchter, 1999). AEC project team members determine the role of discipline-specific knowledge in a cross-disciplinary project-based environment. It is through cross-disciplinary interaction that the team becomes a community of practitioners. Through participation in a community of AEC practitioners students learn how to engage in cross-disciplinary dialogues that require constructing meanings of their design concepts. (Greeno 1998; Dewey 1928, 1958; Lave and Wenger, 1991). It is critical that team members build an awareness, appreciation, and understanding of the other disciplines during this participatory process (Fruchter and Emry, 1999).
This paper presents a study of the relation between activities, media and communication channels, and re-representation in support of common ground building in cross-disciplinary, geographically distributed teams. We formalized the re-representation technique to build common ground that is used by team members during multimodal and multimedia communicative events in cross-disciplinary, geographically distributed settings. We define re-representation as a sequence of representations of the same concept using different communication channels and media. We analyzed the role of re-representation as a communication technique in distributed student teams working on AEC projects, and how re-representation relates to the timeline of the project and their activities. Sharing representations of concepts and building common ground is critical in any project. Re-representation proved to be a key part of the team process. Following are our research hypotheses:

Significant sources of information behind decisions and request for actions are embedded within the dialogue in which participants use both informal and formal media to express their ideas. These communicative events represent the thought process towards decisions are not captured. Capturing this information supports common ground building and accelerates execution of action requests. Re-representations of concepts mediate and accelerate common ground building. Systematic use of intra or inter disciplinary re-representations as part of the team work practice correlate with high team performance, i.e., effective team process and high product quality. We used AEC Global Teamwork course offered in 2008-2009 as testbed to validate our hypothesis.

2 Theoretical points of departure

Communication is central to teamwork. The objective is to ensure that what was said by one member was understood by all the other members. In communication theory this is defined as the process of grounding, or common ground building (Clark and Brennan, 1991). It refers to the development of mutual knowledge, beliefs, and assumptions that is critical for communication between people. To build common ground the dialogue needs to have both the presentation phase and the acceptance phase (i.e., acknowledgement that what was said was understood). Clark and Brennan studied conversation dynamics and offer in common ground theory an instance relevant to our study, called grounding references. One of the techniques to achieve grounding references is through alternative descriptions. Our study builds on these concepts to analyze multimodal and multimedia communicative events in cross-disciplinary, geographically distributed teams.

The design of the AEC Global Teamwork course and information and collaboration technologies (ICT) build on cognitive and situative learning theory. The cognitive perspective characterizes learning in terms of growth of conceptual understanding and general strategies of thinking and understanding (Dewey, 1928). Situative principles characterize learning in terms of more effective participation in practices of inquiry and discourse that include constructing meanings of concepts and use of skills (Greeno, 1998). Since the AEC teams are composed of students from different disciplines, each student acts as a professional in the sense that Goodwin (1994) uses it. Each student brings a different professional perspective to the building design. This is revealed in how they represent and shape the design of the building (Goodwin, 1994). We observed how the team members used their professional representation language in team communication. Their sketches, speech, diagrams, and models were important not just for professional vision or reflection, these external representations formed part of each student’s and the whole team’s cognitive activities. Schon’s and Goodwin’s theories focus on intra-disciplinary activities of practitioner (Schon, 1983; Goodwin, 1994). Our study focused on inter-disciplinary teams. Building common ground and holding a shared representation of the design are critical to achieve a high quality design and team performance.

Other researchers discuss different types of design representations and the significance of hardware, prototypes, and artefacts in developing and conveying ideas (Brereton, 2004; Logan and Radcliffe, 2004). Representations of objects were explored in the context of design and emergence
3 Re-representation technique used in AEC projects

Team members express their ideas, concepts, and proposed solutions using their discipline representation language, e.g., architects use metaphors, sketches, physical models, 2D or 3D CAD models, engineers use equations, diagrams, sketches, 2D or 3D models, simulations, construction managers use spreadsheets, bar charts, 4D CAD models. They use diverse communication channels such as speech, gesture, sketch and media, e.g., audio, video, digital images, etc. The choice of representation determines the level of detail and abstraction necessary to explore or explain a concept. Different representation techniques and media support the exploration of different aspects of the design and direct the focus of the discussion. For instance speech, gestures, sketches or block diagram provide an abstraction level that maintains the necessary ambiguity that allows for exploration and divergent conversations. CAD models offer a level of completion that allows for parametric changes and convergent conversations. Insights are gained by translations from one representation into another of the same concept using diverse media and communication channels.

Similar to the alternative descriptions technique defined by grounding theory and used in conversation dynamics analysis (Clark and Brennan, 1991), we identified the re-representation technique used by team members in multimodal and multimedia communicative events in cross-disciplinary, geographically distributed teams. In the context of our study we define re-representation as a sequence of representations of the same concept using different communication channels (e.g., speech, gesture, sketch) and media (annotation, diagram, drawing, 3D CAD, video) for diverse activities (e.g., explanation, problem solving, etc.). Re-representations determine the breadth and depth of the design process. Re-representation is used in intra- or inter-disciplinary communication. Team members use intra-disciplinary re-representations to express, explore, and better understand concepts, and inter-disciplinary re-representations to explain concepts and impacts across disciplines.

4 Data collection and analysis of AEC communicative events

We used AEC Global Teamwork course offered in 2008-2009 as the testbed. It engaged thirty four students organized in five AEC global project teams. We performed a longitudinal study of the five teams and collected data of their synchronous and asynchronous communication over a period of four months from mid January to mid May 2009. We present in this paper the data collection and analysis of weekly team meetings that took place online using the interactive workspace that included: RECALL collaboration technology and knowledge capture (Fruchter and Yen, 2000). It builds on Schon’s (1983) concept of the reflective practitioner, importance of sketching in communicative events (Tversky, 1999) and gestures (Tang, 1991). RECALL allows user to create free hand sketches, import pictures, or CAD images to annotate them during their discourse. It synchronizes
audio/video and sketches that are indexed and publishes RECALL sessions on a Web server. Users can interactively playback and navigate through the streamed sessions anywhere anytime.

MS NetMeeting Videoconference for application sharing with all the remote sites.

SmartBoard for direct manipulation of content and sketching using the RECALL application.

a Webcam for remote students to see the interactive workspace in PBL Lab at Stanford.

SmartBoard, laptop, or projector VSee™ for parallel video streaming (Chen, 2001).

Weekly project team meetings were two hours long. Multimedia digital data from these meetings was collected using RECALL, digital pictures, and video taping from the PBL Lab where some team members were located. RECALL provided a multimedia information source that synchronized the dialogue in the context of the diagrams, drawings, annotations, text, and written notes. Video provided an overview of people, dialogue, content, gestures, and interactive technology (e.g., SmartBoard) used during the meetings. We captured approximately 150 hours of RECALL weekly team meeting sessions held by the five AEC teams. The authors made real-time observations during the meetings. Observations were also made at the beginning of the class when all the students came to Stanford for five days. We used Video Interactive Analysis (Jordan and Henderson, 1995) and RECALL temporal data analysis (Fruchter, 2001) to analyze the dialogue, activities, artefacts, gestures, sketches of the students as they interacted during their weekly project meetings.

We defined three lenses for data analysis: activity performed by the team members and purpose of the representations being used, media or channel of the representations being used, and whether or not concepts were being re-represented. We distinguished between episodes where the re-representations were intra- or inter-disciplinary. The schema for the activity analysis was defined as follows:

- **Clarifications** – team member who explained a concept in response to a question in order to disambiguate, in contrast to an explanation reply that was triggered by an inquiry question.
- **Explanation** - team member prompted by an inquiry question provide reason behind idea.
- **Exploration** - the team explored alternatives.
- **Problem Solving** - the team solved a specific problem.
- **Closed Questions** - a question that requires a yes/no answer, or a specific numeric data
- **Feedback** - someone gave feedback on what someone else said.
- **Presentation** - team member talked about a subject without being prompted by someone.
- **Negotiation** - the team was discussing the trade offs among possible options.
- **Resolution** - the result of a negotiation in the process of choosing an option.
- **Other** – all the other activities, e.g., technical, scheduling, etc.

For the activity analysis, the RECALL and video footage was broken into segments based on the activity. The length of segments varied from less than a minute to several minutes, with a few cases that were longer than ten minutes. Segments were only categorized if the team was engaged in one of the defined activities, as opposed to technical problems, scheduling, etc. lumped in "other" category.

The activity analysis provided an overview of the transitions and process transformations of the teams over time as they moved through the three project phases (1) needs identification and the project specifications, (2) concept development when the teams explored alternatives, and (3) project development and delivery when the team was focused on detailing, modelling, simulation, life cycle cost, and cost benefit analysis. The results of the longitudinal activity analysis during weekly team meetings indicated variation of time spent engaged in different activities in the three project phases, such as, the significant increase in problem solving from phase one to phase two of the project, and emergence of negotiation and resolution in the third phase of the project. The second lens focused on communication channel and media and used the following coding schema:

- **Speech** – team members talking.
- **Gesture** – body movement that carries information or embodies mental model.
- **Diagram** - image on the screen that carries information, e.g. 2D CAD of a floor plan.
- **Annotation** - add new information to existing diagram, write or draw in the context of the diagram.
• *Highlight* - drawing on a diagram to highlight parts of it, in contrast to annotation.
• *Draw/Sketch* - drawing made on a blank page on screen, whereas an annotation could not.
• *Text* - text that is presented on the screen, e.g., on a power point slide.
• *Writing* - text written on the screen for instance on the SmartBoard.

We integrated the communication channel and activity analysis schemas. The RECALL and video was broken into ten seconds segments. We noted that the speech communication channel was continuous and accompanied almost all other media representations. This integrated data analysis highlighted switching between activities and mix of communication channels and media in support of the different tasks during the team meetings in the different project phases. The results were further analyzed to identify re-representation episodes. The transcript of the discourse and screen shot images were added to the results spreadsheet of the data analysis.

Figure 1 illustrates a re-representation example during a cross-disciplinary explanation episode between architect and structural engineer. They discuss the impact of the architectural design on the structural behaviour, i.e., the large cantilevers that have different dimensions and are placed on two sides of the building. The engineer first uses a building elevation diagram showing two cantilevers (Figure 1a). It has diagrammatically marked with red lines possible solutions such as tension cable or truss systems to address the problem. To better explain the structural concepts and challenges the engineer uses a second diagram showing the forces (Figure 2a). He explains the structural behaviour and potential collapse situation by annotating and highlighting elements on the diagram. The engineer uses a third diagrammatic representation to further explain the problem and the need for architectural symmetry based on same span sizes for the two cantilevers. He explains by annotating and drawing on the diagram to support his rationale and possible solution based on architectural and structural symmetry (Figure 1c). The architect is very responsive and tries to paraphrase the engineer’s explanation using yet another fourth re-representation of the problem and solution. He uses a new blank page to draw using his architectural representation language - drawing rectangles to represent the different volumes of the building (Figure 1d) - and to ensure he understood the engineers’ request and reached common ground saying: “If we have an ideal building for the architecture to work with the structure, you are asking me to unify the volume of the large classroom and the volume of the offices with a core building and design the cantilevers with the same dimensions, right?” The engineer replies: “Yes, that would be amazing.” The architect agrees and indicates “OK. I will go back and redesign the building. I take it as a positive challenge and feedback.” As defined by grounding theory, the re-representation used by the engineer illustrates the presentation phase, and the architect’s re-representation shows the acceptance phase in building common ground. The architect’s acceptance is an explicit indication that what the engineer explained was understood and a plan for action.

Re-representations were used to support different activities in the various project phases. In the first and second project phase re-representation was mostly used during explanation, exploration, problem-solving to build common ground. During the third project phase re-representation was mostly used during justification, clarification, negotiation, and decision making. The integrated data
analysis of the activities and communication channels revealed that re-representation mediates communication and explanation of concepts and plays a key role in common ground building.

5 Conclusions

A better understanding of how, when, and why representations and re-representation of concepts are used, can provide insights into the complexity of the discourse in global teams and the critical relationship between communication process, activities, communication channels and media.

Regular use of RECALL during meetings enabled building common ground and captured issues in context in order to be shared with team members who could not attend a meeting. Based on that, the team members could act and revise the design. In a typical project, where such knowledge source is not available, requests for clarification cycles delay the process. Such scenarios validate the first hypothesis that capture, sharing, and replay of multi-media communicative events facilitate common ground building and accelerate execution of action requests.

Typical scenarios of common ground building using re-representation took between ten and twenty minutes, e.g., from identifying a design issue, explanation of the problem through a sequence of re-representations, to acknowledgement of built common ground, and reaching a resolution and plan for action. This supports the second hypothesis re-representations of concepts mediate and accelerate common ground building. Teams that did not use the re-representation required weeks to take action, and in some cases the design was not revised leading to increased cost and lower design quality.

Data analysis results support the third hypothesis, i.e., use of intra or inter disciplinary re-representations correlate with team performance, i.e., team process and product quality. The top two teams who used extensively the re-representation technique to build common ground reached a high performance team process and produced high quality design and construction proposals. One team won the Swinerton Sustainability Challenge competition, and the second team was the runner up.

References


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