4th Construction Specialty Conference
4e Conférence spécialisée sur la construction

Montréal, Québec
May 29 to June 1, 2013 / *29 mai au 1 juin 2013*

Interactions with BIM Tools in Design Coordination Meetings

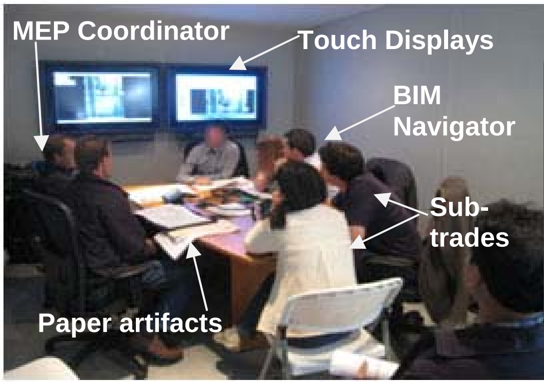
Sarmad Mehrbod[1], Sheryl Staub-French[1], and Melanie Tory[2]
[1]Department of Civil Engineering, University of British Columbia, 6250 Applied Science Lane, Vancouver, BC (V6T 1Z4). [2]Department of Computer Science, University of Victoria, P.O. Box 3055, STN CSC, Victoria, BC (V8W 3P6).

Abstract: Design coordination and conflict detection are one of the most common and highly valued uses of Building Information Modeling (BIM). However, in our observations of these meetings, we have found that BIM tools are not being fully utilized. Navigation is still a challenge and participants often revert back to 2D drawings even when BIM tools are readily available. To better understand the challenges of interacting with BIM, we conducted an ethnographic field study to examine how a building design team used BIM tools to coordinate the design. We observed and analyzed weekly coordination meetings in our BIM trailer equipped with two large touch screens that displayed 2D and 3D information representations. These meetings were recorded and analyzed qualitatively to understand the challenges of utilizing BIM tools in these meetings. We found that transitions between physical and digital design artifacts were frequent, and that navigation with digital artifacts was often inefficient. Based on this analysis, we coded and analyzed the meetings quantitatively to investigate why and how often the transitions between different views and design artifacts occurred. We also analyzed the reasoning behind these transitions as well as the navigation techniques used with each design artifact.

1. Introduction

In complex building projects, design coordination is a critical and challenging task. The process is essential as critical design decisions are often made in these meetings, such as determining the location of critical mechanical equipment and resolving clashes between systems. Recent advancements in Building Information Modeling (BIM) tools have had a significant impact on the efficiency and efficacy of the design coordination process. Studies have shown that design coordination and conflict detection with BIM is one of the most frequent and valued uses of BIM in the construction sector (McGraw Hill 2012). Communication of project information through paper-based information representations limits the team's ability to work together, to solve problems and make decisions during design meetings (Fischer et al. 2002). In contrast, teams using BIM tools for MEP coordination are found more likely to be satisfied with the meeting process and spend less time arguing over issues compared to paper based design coordination meetings (Liston et al 2007).

Despite the many advantages of BIM in design coordination, previous studies (e.g., Tory et al. 2008, Liston 2009) and our own observations of numerous design coordination meetings have found that interacting with BIM tools during these meetings is still a challenge. In particular, we observed that *navigation* in the BIM environment is still a significant challenge, and that practitioners often *transition* between multiple design artifacts, often reverting back to 2D paper-based drawings even when BIM tools are readily available. Figure 1 highlights a 5 minute meeting segment from a design coordination meeting we observed (the following section will elaborate on this further) that demonstrates the navigation challenges, and the numerous transitions between design artifacts that are required to identify and resolve potential conflicts between building systems. We believe the challenges with navigation and the frequent transitions between design artifacts are limiting the participants' ability to interact with the design artifacts efficiently and effectively.



-- MEP Coordinator (**C**) refers to the PDF view of the mechanical info and asks:
"Where can we put the sanitary line?"
-- The Mechanical Rep refers to his paper drawing: *"on the west side, here!"*
-- **C** walks to the display and sketches the sanitary path on top of the mechanical 2D PDF file.
-- **C** asks the BIM navigator (**N**) to show the 3D view.
-- **N** zooms and makes objects transparent.
-- **C** loads the east elevation screenshot of the view.
-- **N** Changes his view, zooms in, walks along the cable tray, creates a box around the model & turns off the electrical model.

Figure 1: Meeting environment (left) and a 5 minute segment (right) from a design coordination meeting showing the frequent interactions with different 2D and 3D digital and physical artifacts.

This research examines how a project team used representational design artifacts during design coordination meetings on a complex fast-track building project. Specifically, we characterize how meeting participants interacted with 2D digital drawings, 2D paper-based drawings, and 3D BIM tools, identify the type and frequency of transitions between the different artifacts and specific representational views, and analyze participant's motivation or intent in utilizing the different types of artifacts. Our findings indicate that participants had the richest range of interactions with 3D BIM tools, interacted more frequently with 2D digital and paper drawings, and frequently transitioned between paper-based and digital artifacts.

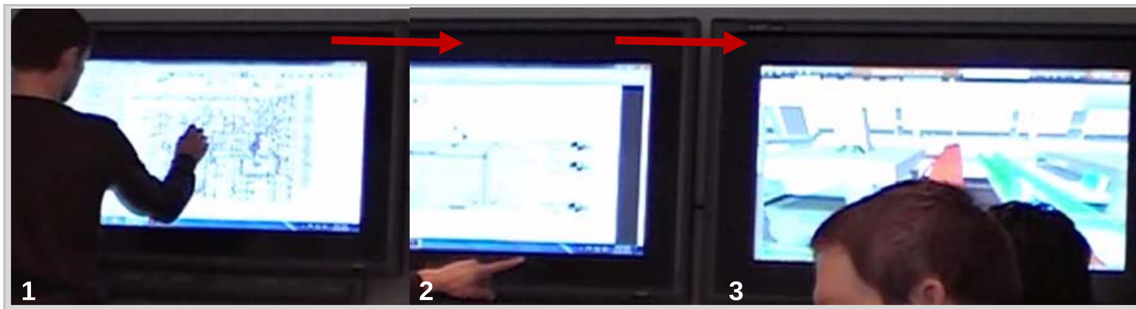
2. MOTIVATING CASE STUDY

We performed an ethnographic field study of the design coordination process on the newly constructed Pharmaceutical Sciences Building at the University of British Columbia, Vancouver campus. The 18,000 m^2 facility provides a variety of teaching and learning spaces from lecture halls and seminar rooms, to a pharmacist clinic and three floors of research laboratories. Construction of the project started in June 2010 and the building was delivered on time for occupancy in September 2012. The project had considerably complicated MEP systems along with a unique architectural design, which made design coordination and constructability the key concerns for this fast track project.

Over the course of design and construction, BIM was used extensively to coordinate designs from different consultants and sub-trades. Since the beginning of construction weekly meetings (November 2010 to July 2011) were held in our BIM Trailer on the construction site. The BIM Trailer (Figure 1- left) was equipped with two large-screen touch displays, connected to separate computers displaying 2D and 3D digital information. In terms of the software used, PDF's were used to display 2D digital information, Autodesk Revit was used to modify 3D digital information, and Autodesk Navisworks Manage was used to navigate through the integrated 3D model. The Smart software on the Smartboards enabled the participants to draw in multiple colors, erase, save screenshots on top of any software displayed, and use panning techniques to navigate through what was on display. Each participant had a display port installed on the table so that they could connect their laptops to the wall displays. In addition, the participants often brought their own set of paper drawings to the meetings. The meeting participants consisted of representatives from the different trades involved in the project, including the owner, the construction manager, architect, engineering consultants and construction sub-trades. Although not everyone could participate in the weekly meetings, the meetings always had at least six active participants and in most cases the MEP coordinator and the BIM navigator were present. On some occasions, when a participant was not present, they participated remotely through conference calls or online video conferencing tools.

Use of state of the art BIM tools facilitated the interactions with 2D and 3D digital information during the meetings that contributed to the effective use of BIM throughout the project. However, our findings indicated that participants interacted with 2D digital and paper-based design information for the majority of meeting time. Issues arose when participants required interaction with 3D digital information at the same time or without the BIM navigator's help (Figure 2 left). We also observed a number of navigation and modification techniques with these tools during the meetings. For instance, the BIM navigator used special shortcuts and techniques to interact with the BIM tools throughout the meetings.

Figure 2 represents a five-minute segment form an observed meeting. On this occasion, the BIM navigator performed interactions for one minute, and the next four minutes were spent accommodating the mechanical representative and architect's needs. Specifically, the BIM navigator used different interaction techniques with the BIM tools and other participants tried to interact with these tools remotely or by changing their location to better facilitate interaction. We also observed many transitions between design artifacts or views, which seemed inefficient. Figure 2 (right) shows another five-minute segment from the same meeting. In most cases, these transitions were performed to obtain different views or to obtain design specific information. Although the transitions were necessary, in this case it took approximately five minutes to complete these transitions and get back to the main discussion topic.



The navigator uses section codes and Grids to find a clash. He zooms in, makes some objects transparent, changes view back and forth. He turns off the structural model to see the clash clearly.
- Mechanical Sub trade asks navigator to change view angle & walk on a cable tray.
- The architect switches his seat & takes over BIM. He struggles to interact with it.

While discussing a clash on paper drawings:
- The BIM navigator (N) shows clash in 3D.
- N loads another view of the elements.
- MEP Coordinator loads the east elevation Screenshot on 2nd display to check levels.(pic 2)
- N changes his view and walks along cable tray to find another clash section. (pic 3)

Figure 2 - Top: displays showing interaction with 2D and transition from 2D to 3D digital information. Bottom: Challenges of participants interacting with 3D Digital tools (left) and transitioning between information representations (right).

We have come to understand the design coordination problem space as having three inter-connected dimensions: Artifacts, Interactions, and Transitions (Figure 3). This research explores the relationship between these three dimensions to gain a deeper understanding of how these factors influence each other and affect the efficacy of these meetings.

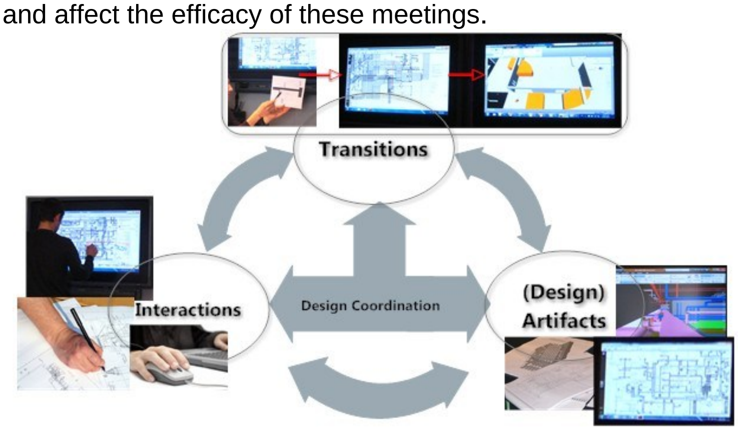


Figure 3: Our interpretation of the design coordination problem space consisting of three dimensions: Artifacts, Interactions and Transitions.

3. Theoretical Motivation

In this section we briefly cover the related literature in three different domains: use of design artifacts, interactions with design artifacts, and transitions between different views and artifacts. In the field of interactions with design artifacts, Liston et al. (2007) studied the role of media use in team interactions. They observed & analysed different teams during MEP coordination meetings qualitatively, and found that teams using BIM tools for MEP coordination were more likely to be satisfied with the meeting process and spent less time digressing with issues compared to paper based design coordination meetings. Their observation methodology for design coordination meetings was in some ways similar to this study since they studied teams using BIM for design coordination in a similar meeting environment. We have also been able to apply their qualitative data collection approach (collecting short video segments from each meeting to capture details) in our early qualitative observations to capture and identify our focus area. However, their study did not analyze low level participant interactions with design artifacts in detail, and focused more on comparing performance of different teams using design artifacts.

Tory et al. (2008) conducted a field study to understand how meeting participants used representational artifacts for building design coordination. They found gesturing, navigation, annotation and viewing as the four primary interactions with design artifacts. They identified bottlenecks in the process when participants attempted to navigate digital information, interact with wall displays, and access information individually and as a group. They developed a framework and their research outcome for navigation, annotation, and viewing techniques helped us to identify various interaction techniques with 2D digital and physical design artifacts. We built on their framework for constructing our codes when analysing the low level interactions with 2D digital and physical design artifacts (e.g. borrowed the terms 'Airdraw' and 'Highlighting'). However, their study was quite limited in its analysis of interactions with BIM tools because participants rarely used BIM tools in their meetings).

In the domain of design artifacts, the role of visual reorientations and the interactions between physical and digital design artifacts was examined extensively by Henderson (1999). Although Henderson found sketches as the most important interaction as they enabled visual thinking, revision, and communication among designers, her studies were mostly focused on engineering design meeting environments in all disciplines.

Few research efforts have investigated the transitions between different views and artifacts. One noteworthy effort was the JUMP project (Terry et al. 2007). The JUMP project developed a novel set of tangible tools to navigate and interact with design artifacts using 2D augmented technical drawings. In JUMP, filter tokens were placed on top of paper drawings to access the 2D visualization of electrical, mechanical, and structural design information. Although JUMP provided a novel approach to facilitate the transitions from paper to 2D digital information, the practicality of using physical tokens to drive the transitions has not been tested on construction projects.

The above prior studies have focused on design coordination at a higher level of abstraction, representation, processes of design, and characterizing all interactions with design artifacts. However, a few have specifically studied the design coordination process and the lower level participant interactions with design artifacts (especially BIM tools) to Identify navigation and modification mechanisms or to understand the transitions between different artifacts and views as well as participants motivation to make these transitions during design coordination meetings. Our study addresses these gaps in current literature.

4. Methodology

We participated in and recorded design coordination meetings from the early stages of design through construction of the building systems on the UBC Pharmaceutical building project. We recorded over 43 design coordination meetings of which 32 meetings were held in our BIM trailer. We conducted a qualitative assessment of the meetings initially to determine our focus area for a detailed analysis. Next, we further analyzed the data and performed a retrospective quantitative and qualitative assessment through coding selected meetings and segments to capture detailed information regarding participants' interactions with and transitions between design artifacts.

Qualitative Assessment: We first analyzed the recorded meetings qualitatively to understand the participants' interactions with design artifacts, and to better understand the efficiency and flow of the meetings. We observed all meetings based on the following: number of participants present, issue being discussed, stage of project, interactions with artifacts, and final outcomes. We gathered our qualitative observations through the creation of five minute segments (or vignettes) of the selected meetings, and then analyzed the interactions with the artifacts and identified any bottlenecks. We then further investigated the participants' interactions with design artifacts using Grounded Theory (Glaser and Strauss 1967; Glaser 1992) to create analytic codes and derive categories from the meetings (Charmaz 1995, 2001). In addition, we analyzed the conversations to understand the context and reasoning behind the interactions. The results from this section determined our focus area for a more rigorous quantitative assessment.

Quantitative Assessment: We conducted a rigorous quantitative assessment of the meetings to understand the participant's interaction mechanisms and transitions between different design artifacts. Initially, we transcribed all conversations and participants' behaviours of two 90 minute long meetings and later on we transcribed a number of five minute segments from other meetings with the highest interaction ratio. The meetings were chosen based on the same criteria as our qualitative assessment, and for this analysis we transcribed and analysed a total of 300 minutes of building design coordination meetings.

In terms of our approach, we used open coding similar to Tang (1991). We fully transcribed all participants' interactions and their discussions. We then used both qualitative and quantitative techniques for our data collection and content analysis (Neuendorf 2002). We used in-vivo coding scheme (coding terminology was derived from actual phrases in specific text segments) in order to borrow terms from transcriptions for our coding structure categories (e.g. boxing, zooming, and grids). We then followed Yin's (2003) approach to categorize our codes and create a database of codes. This database was later used to trace the analytical results back to raw data to verify the data collection and compare observations between each meeting (Yin 2003).

5. Results

5.1 Interactions with Design Artifacts

At first, we studied the participant's interactions with design artifacts. We identified the design artifacts present and categorized them into three categories: 2D Physical (paper drawings, printed screenshots, and logbooks), 2D digital (pdf and screenshots), and 3D digital design artifacts (Revit and Navisworks). Each of these categories had their own subcategories of design artifacts. Figure 4 represents our findings in terms of the percentage of time participants interacted with each design artifact during the meetings. As shown, the participants utilized all design artifacts and each category of artifacts was in use for an almost equivalent portion of time. In addition, the analysis also showed that some of the specific forms of information were utilized more than others within the same category. For instance, when participants accessed 3D digital information they accessed 3D Navisworks most of the time (59%).

In addition, we investigated the types and frequency of participants' interactions with each specific design artifact. We started this stage of the analysis by investigating the interactions with 3D digital information and found 17 types of navigation and interaction techniques with BIM tools. Table 1 shows these findings along with their description. Table 1 also shows the total number of instances of each interaction throughout all the analysed meetings (300 minutes). As discussed previously, we used in-vivo coding scheme for our interaction terminology. For instance, we named the act of making 3D objects transparent as “Visibility”.

In addition, to identify the frequency of these interactions, we recorded each interaction instance, and analysed the total number of interactions throughout all meetings. As Table 1 represents, the top five interactions with 3D digital information were made through Navisworks to obtain different views of the BIM and to navigate through the model. Also, we observed that ‘changing viewpoint’ and ‘zooming’ were the most frequent interactions participants made with design artifacts.

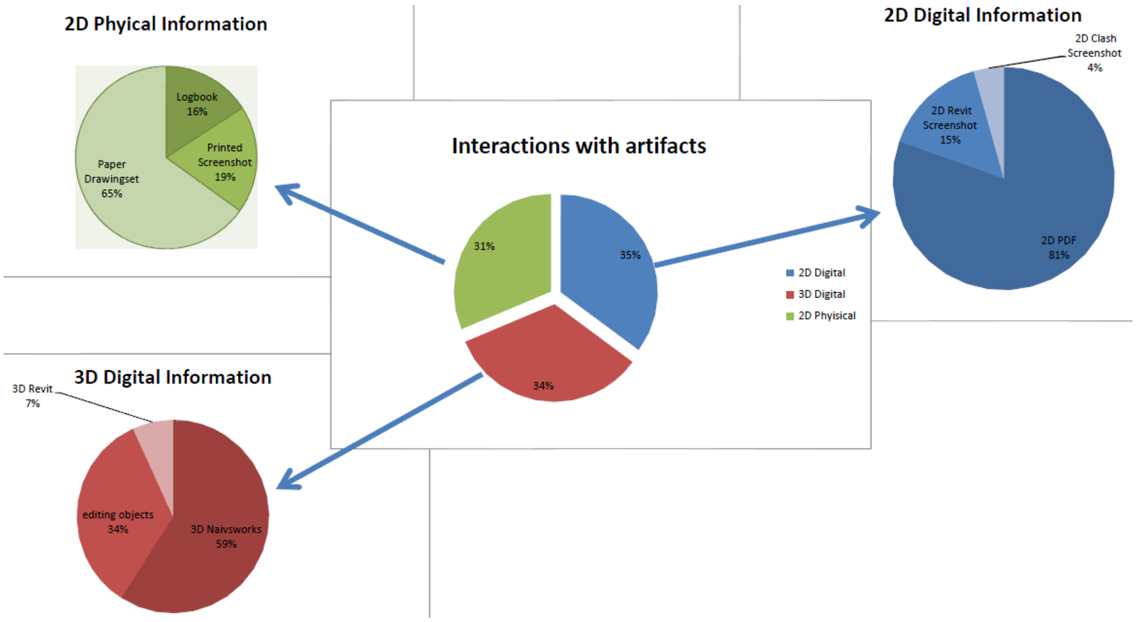


Figure 4: Interactions with artifacts during meetings (% of time)

Since our findings indicated that participants interacted with 2D digital and physical design information nearly 2/3 of the meeting time, we chose to study and characterize the interactions with each of these information representations to identify the most useful interactions with these artifacts. We then investigated the interactions made with each design artifact separately to gain a deeper understanding for why these interactions were necessary. Figure 5 (left) represents the interactions with 2D digital information along with the frequency of each interaction. As shown, sketching on top of the drawings (mainly on the 2D PDF files) was the most frequent interaction with 2D digital information. Also, switching back and forth between PDF files, navigation of 2D digital information, highlighting (with a mouse, finger or pen) and saving screenshots were the most frequent interactions with 2D digital information.

Table 1: Interactions with 3D digital information, their description and frequency.

Interactions	Description	Frequency
Change viewpoint	Adjust the viewpoint	
Zoom	Zooming in /out	
Save / load views	Bookmarking and recalling specific 3D views	
Section	Insert sections in BIM for easier navigation	
Walk-thru	Walking through the BIM along a path	
Hide / Unhide models	Turn off / on models and objects	
Use Grids	Use of Grids for easier navigation	
Review Clash Detection	Locate previously found clashes	
Modify	Modify objects in real-time	
Save Screenshot	Capture the current view or sketch	
Color Code	Use of different colors for each trade's model	
Highlight	Highlighting a path using pen, hands or mouse.	
Assuming geometry	The BIM is missing geometry of an element.	
Update 3D model	Export updated 3D model for Clash detection	
Visibility	Make objects see through	
Identify Clash detection	Finding Clashes not detected by the software.	
Execute Clash Detection	Run Clash Detection with the updated model	

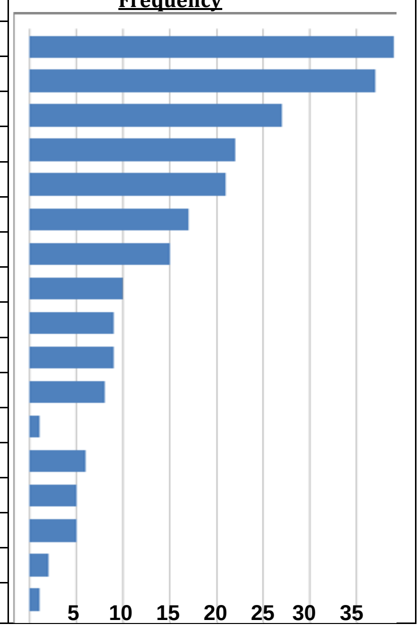
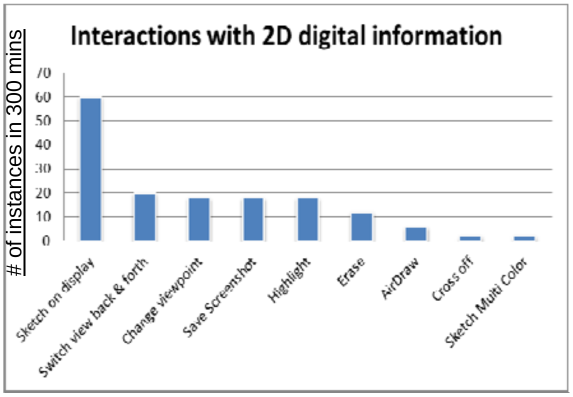


Figure 5 (right) shows the interactions with 2D physical design information (i.e. paper-based artifacts) along with the frequency of each interaction. Paper artifacts were used numerously to provide dimensions of different design components. During the meetings, participants often exchanged their paper drawing sets, or lifted up the drawings or leaned over them to have a better look at the paper artifacts (which we refer to as 'physical zooming'). Sketching and measuring on paper were also frequently used during the meetings.



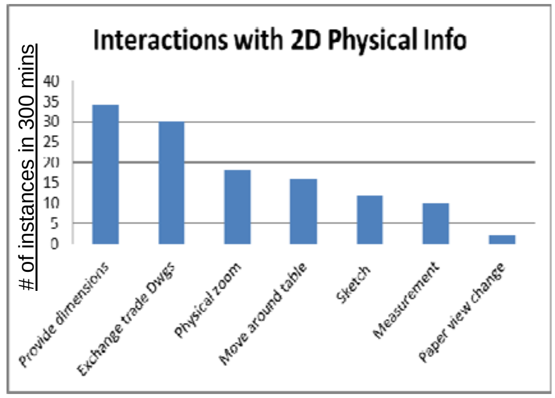


Figure 5 (left): Interactions with 2D digital information and their frequency.
Figure 6(right): Interactions with 2D physical information and their frequency.

The next section describes our analysis of the transitions made between different design artifacts during the design coordination meetings observed.

5.2 Transitions between Design Artifacts

The second part of our study focuses on conducting a qualitative and quantitative assessment of the transitions during these meetings. We identified 28 transition types between different design artifacts and views. In our terminology for coding the transitions, we used the in-vivo coding approach and recorded software specific view name codes for each transition. For instance, we used the "2D PDF to 3D Navis" terminology to refer to a transition from a 2D digital representation in a PDF format to a 3D digital representation in Autodesk Navisworks. We also made the code names shorter by abbreviating some terms. For instance, we used "paper" to refer to participants' paper drawing set.

Transitions occurred frequently throughout the meetings. For instance, during one meeting (90 minutes) we captured over 50 transitions between various views and design artifacts. Figure 7 presents the frequency of each transition during all analysed meetings along with their frequency of occurrence. In order to better present our findings, we have categorized the frequency of the transitions into 4 different categories: very frequent, frequent, less frequent and rare. Each arrow represents a transition and the weight (thickness) of the arrow represents its frequency category. As illustrated, transitions from PDF views to other design artifacts and from other design artifacts to PDFs were the most frequent transitions during the meetings.

Once all transition types were identified, we conducted a qualitative assessment to investigate the reasons influencing participants to transition from one form of information representation to another (**Error! Reference source not found.**). We found 14 leading reasons which influenced participants to make these transitions. We characterized these reasons into four main objectives or motives, including obtaining a better view, obtaining further information, performing modifications, and quickly accessing information. We further attempted to characterize the reasoning behind the transitions by identifying the frequency of each reason. This classification technique helped us to understand and capture the most influential reasons for transitions during meetings.

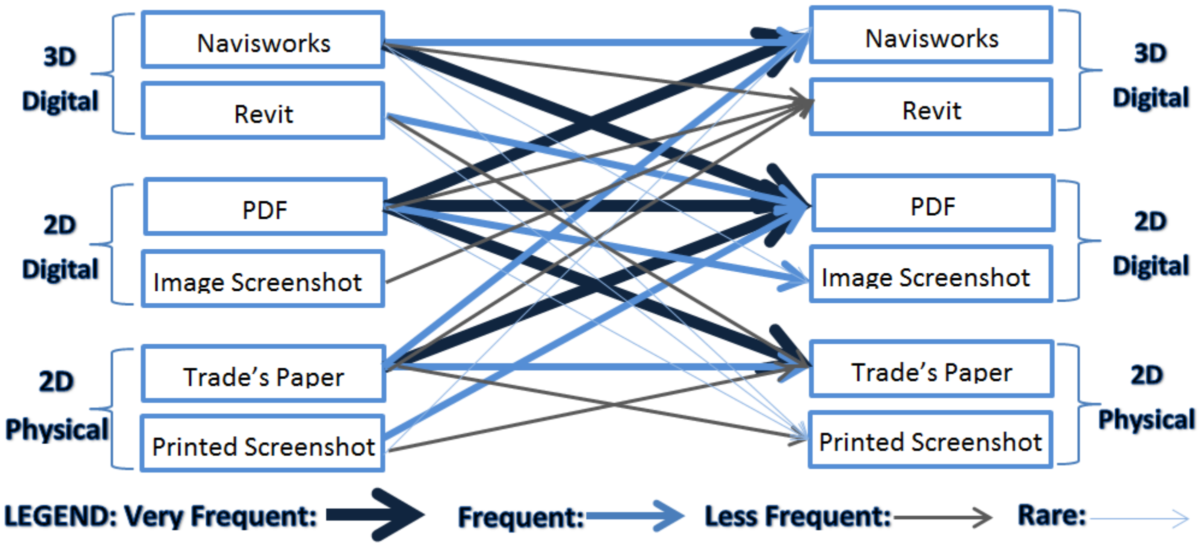


Figure 7: Transition types and their frequency.

To obtain a deeper understating of the relationship between the causes and the transitions, we investigated the relationships between the most frequent transitions versus the reasons (motivators) for these transitions. Our findings indicate some of the major motivations leading to each transition. For instance most of the transitions from 2D digital information (in PDF) to 3D digital views (in Navisworks) were made to obtain a better a view of the elements during discussions. Also most of the transitions from 2D PDF view to 2D PDF view were made to see other Trade's models and the understand coordination issue in more detail. Furthermore, the transitions from 3D Navisworks to pre-saved 3D views were made to see surrounding objects and to better understand the coordination context. The next section discusses the results of this analysis in more detail.

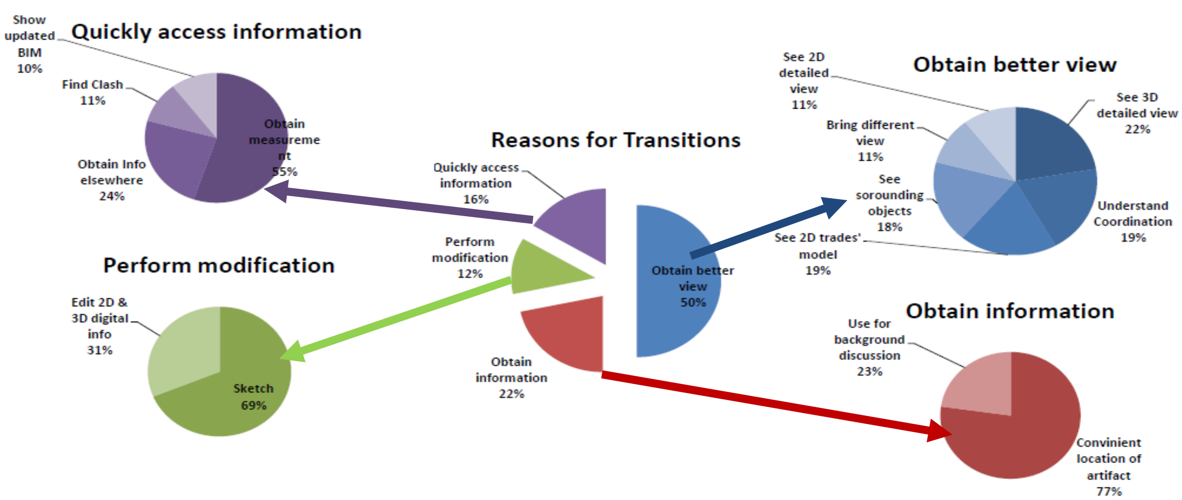


Figure 8: Characterization of reasons behind transitions and their frequency.

6. Discussion

We found the richest range of navigational interactions with state of the art BIM tools. We also found a wide range of interaction techniques with 2D digital information, and found the least range of interaction with 2D physical information. However, our findings were surprising in terms of the portion of time participants interacted with 2D digital and 2D physical information (2/3 of the meeting time) even though state of the art BIM tools were readily available. We believe this was due to the challenges some participants had with interacting with BIM as well as the wide range of transitions between different design artifacts. Our findings indicate that most transitions from 3D digital information to other artifacts were made to obtain measurements, access detailed 2D views and trade-specific information, and sketch on top of artifacts.

During the meetings, some participants performed a range of navigation and modification interaction techniques with BIM tools. While the BIM Navigator and MEP Coordinator were very experienced and efficient interacting with 2D and 3D digital information, for other participants the learning process often took longer and participants' interaction level varied per person. Not all participants could access the BIM or 2D digital information so they often had to access information through a medium (e.g., the navigator or coordinator). In some cases they walked to the displays or switched their seat with the navigator to interact with 2D and 3D digital information. In addition, while the screens were very helpful to visualize the information, having them far away from the participants often made access to the artifacts very difficult. Each participant had a display port installed on the table in front of them, but they rarely used this feature on the table and most of the time the screens were in use by the MEP Coordinator and BIM Navigator.

In terms of transitions between different views and artifacts, our findings indicate that 47% of the transitions were made from 2D digital information, 30% of the transitions were made from 3D digital information, and 27% of the transitions were made from paper based artifacts to other design artifacts. These findings demonstrate that 2D digital information was the starting point for almost half of the transitions during the meetings, which was surprising. Furthermore, we observed that the need to transition frequently was time consuming and disruptive, often slowing meeting progress.

We also explored the relationships between design artifact, interactions and transitions. We found that the correlation between three dimensions affect the efficiency and efficacy of the meetings directly. For instance in the segment shown in Figure 1, an enquiry leads to a transition for obtaining trade-specific information, which then leads to another transition to interact (sketch) with 2D design information, and then to another transition to better understand the coordination context which often led to interactions with the BIM. We also found that the dimensions sometimes directly affect each other, for instance, by comparing different segments within a meeting we found that when there were less transitions involved in the meetings, the level of interaction with design artifacts improved significantly and when there were more transitions involved, the efficiency and interaction level with artifacts seemed to decrease.

7. Conclusions and Future Work

We have conducted an ethnographic field study examining the low level interaction techniques of participants in a series of design coordination meetings with 2D physical, 2D digital and 3D digital design information. We characterized the interactions with the design artifacts and investigated the types and frequency of transitions between views and artifacts during the meetings along with participants' motivation to make these transitions. We also investigated the relationships between artifacts, navigation and transitions and identified correlations between these dimensions that further help to understand the challenges with BIM-based design coordination.

In terms of future work, we plan to conduct another ethnographic field study with a different design coordination team on a different project to validate the generality of these findings. In addition, we believe our findings from this study could be further extended into a set of guidelines informing the development of future systems for BIM-rich environments. Our next step will involve implementing some of these guidelines in a prototype tool to address some of the shortcomings identified in this study, facilitating more effective and efficient use of BIM in building design coordination meetings. We also plan to conduct user studies in our BIM trailer to test the prototype tool in a realistic setting.

8. References:

Charmaz, K. (2001). *Qualitative interviewing and grounded theory analysis.* In J. Gubrium & J. Holstein (Eds.), Handbook of interview research: Context and method (pp. 675-694). Thousand Oaks, CA: Sage.

McGraw Hill Construction (2012). SmartMarket Report, *The Business Value of BIM 2012.* , McGraw-Hill Construction, Bedford, MA.

Fischer, Martin, Maureen Stone, Kathleen Liston, John Kunz, and Vibha Singhal (2002): *Multi-stakeholder collaboration: The CIFE iRoom.* In Proceedings of the CIB W78 Conference, Distributing Knowledge in Building, Aarhus, Denmark, June 12–14, 2002.

Glaser, Barney and Anselm Strauss (1967): *The Discovery of Grounded Theory: Strategies for Qualitative Research.* Chicago: Aldine Transaction.

Glaser, B. G. (1992). *Emergence vs forcing: Basics of grounded theory analysis*. Sociology Press.

Gross, Mark D., Stephen Ervin, James Anderson and Aaron Fleischer (1988): *Constraints: knowledge representation in design*. Design Studies, vol. 9(3), pp. 133–143.

Henderson, Kathryn (1999): *On Line and On Paper: Visual Representations, Visual Culture, and Computer Graphics in Design Engineering.* Cambridge: MIT Press.

Kunz, John, Martin Fischer, Kathleen Liston, Vibha Singhal, and Maureen Stone (2002): *Virtual design and construction in the CIFE iRoom*. In Proceedings of the 3rd International Conference on Decision-Making in Urban and civil Engineering, London, England.

Liston, K., Fischer, M., Kunz, J., and Dong, N. (2007). "*Observations of two MEP iRoom coordination meetings: An investigation of artifact use in AEC project meetings.*" CIFE working paper, Stanford Univ. Stanford, Calif., 59.

Liston, Kathleen McKinney. (2009) *A mediated interaction approach to study the role of media use in team interaction*. Ph.D. Thesis, School of Civil and Environmental Engineering, Stanford University, Stanford, California.

Neuendorf, K. A. (2002). *The content analysis handbook*. Thousand oaks, California: Sage.

Tang, John C. (1991): *Findings from Observational Studies of Collaborative Work.* International Journal of Man-Machine Studies, vol. 34, pp. 143–160.

Terry, Michael, Janet Cheung, Justine Lee, Terry Park, and Nigel Williams (2007*): Jump: A System for Interactive, Tangible Queries of Paper*. In Proceedings of Graphics Interface, Montréal, Canada, pp. 127–134.

Tory, M., Staub-French, S., Po, B. A., & Wu, F. (2008). *Physical and digital artifact-mediated coordination in building design*. Computer Supported Cooperative Work (CSCW), 17(4), 311-351.