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CHARACTERIZING BOTTLENECKS IN BUILDING DESIGN COORDINATION MEETINGS

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Abstract: We conducted an ethnographic study of design coordination meetings to better understand the challenges faced by project teams as they coordinate designs in multi-disciplinary meeting environments. This ethnographic study involved observation and analysis of twenty-seven design coordination meetings from the design development phase of a high performance institutional research building. Design coordination and conflict detection are two of the most common and highly valued uses of Building Information Modeling (BIM). However, in our observations of these meetings, we found that BIM tools were extremely under-utilized. This research identified and characterized the bottlenecks encountered during these in-person design coordination meetings. We observed meeting bottlenecks when meeting activities were performed inefficiently, when the meeting process was slowed down, when meeting workflow was interrupted, or when decision-making was hindered. We identified and characterized meeting bottlenecks in a framework that illustrates the nature of each bottleneck and the frequency of its occurrence. According to our observations, we identified five types of bottlenecks that hindered the efficiency of design coordination meetings: people, meeting environment, drawings, interaction/access and information. We anticipate that these findings will help to inform the development of better meeting processes, the design of new interaction, visualization, and integration technologies that better support the meeting processes of design teams.

1. INTRODUCTION

During the design phases of a project, design teams meet regularly to control and monitor the design process, to share design information, and to coordinate the various disciplines' designs. The system designs are iteratively updated to accommodate each discipline's requirements. Successful management of this design process is critical to the efficient delivery of cost-effective and quality projects (Chua et al. 2003). Coordination among stakeholders is critical to ensure that a design meets the functional, aesthetic, and economic requirements of the owner. Timely delivery of a coordinated design and a less problematic and on time construction process also depends on the effectiveness of the coordination meetings. However, Liston et al. (2007) found that teams spent only 20% percent of time on "coordination" activities. The remainder of the meeting time was spent for "direct discussion of design" (50%), "taking stock", "digression and other" project activities. Although digital technology has become integral to the design process, design coordination is often still accomplished using paper printouts of 2D schematic diagrams and other related project information. However, there are limitations of paper for coordination. Design coordination is challenging and needs to be understood so it can be better managed.

This paper presents the results of a long-term ethnographic field study that investigated the challenges faced by project teams as they coordinate designs in multi-disciplinary meeting environments. This study involved observation and analysis of twenty-seven design coordination meetings from the design development phase of a high performance institutional research building over 16 months. We identified and characterized meeting bottlenecks in a framework that illustrates the nature of the bottleneck and the frequency of its occurrence. We observed meeting bottlenecks when meeting activities were performed inefficiently, when the meeting process was slowed down, when meeting workflow was interrupted, or when decision-making was hindered. According to our observations, we identified five types of bottlenecks that hindered the efficiency of design coordination meetings: people, meeting environment, drawings, interaction/ access, and information.

2. LITERATURE REVIEW

This section summarizes relevant literature on group work, coordination meeting challenges, and group decision making. Group decision making is a complex process in construction given the fragmented nature of the construction industry, the barriers set up by traditional contractual relationships, and the conflicted roles and responsibilities of project teams (Issa et al., 2006). In Grønbæk et al. (1993), the bottlenecks in daily work and collaboration were divided into three subsections: bottlenecks related with sharing materials, coordination and communication. Liston et al. (2001) looked at challenges in visualization, sharing, exchange and interaction with the electronic information in multi-disciplinary project team meetings. Their main focus was on interactive information workspaces. When compared to this study; rather than documenting overall meeting bottlenecks, the paper proposed an approach for dealing with a number of specific bottlenecks. Tory et al. (2008) described meeting bottlenecks related to navigating digital information, individual information lookup, and accessibility of information. However, this work was focused on low level interactions with artifacts rather than high level meeting processes. These different efforts provided important points of departure in terms of understanding the different types of bottlenecks that we were observing in building design coordination meetings.

An important consideration in design coordination is that project teams must contend with numerous and diverse types of information. The participants use a variety of visual representations of project data in different formats (paper and digital documents, physical models, sketches etc.), to convey information within the group. Participants share, view, coordinate, and manage design information during coordination meetings. Several research efforts focused on activities performed by meeting participants in workspaces. In their study of small group design meetings, Olson et al. (1992) categorized meeting activities as issue, alternative, criterion, project management, meeting management, summary, clarification, digression, goal, walkthrough and other activities. In a subsequent study, Liston et al. (2001) built on this categorization of meeting activities and classified meeting activities as descriptive, explanative, evaluative, and predictive.

Luck (2007) investigated artifact use in design and described how artifacts are used to mediate understanding in design conversations between people with different levels of understanding of design schemes. Luck concluded “it was only through the use of these artefacts and conversation about these artefacts that the users’ understanding of the design became explicit”. Meeting discussions mostly evolve around different forms of information artifacts. Participants interact with information in numerous ways, including pointing, mark-up, changing (Liston et al. 2007), and perform physical interactions, such as gestures, annotation, and navigation (Tory et al. 2008). Tory et al. (2008) described how a building design team used design artifacts during design coordination meetings as part of an effort to identify effective input methods for a digital system. They presented possible directions for future Computer Supported Collaborative Work (CSCW) technologies based on observations, like simplifying and enhancing navigation, design mechanism for digital bookmarking, enriching pointing techniques, augment pen functionality and supporting information access by both groups and individuals. Researchers have also recognized that group dynamics play an important role in collaborative work and may have a significant impact on meeting performance (e.g., Nunamaker et al. (1991) and Garcia et al. (2004).

This research builds on previous efforts mentioned in this section by developing a taxonomy of bottlenecks that captures the social, contextual and technical aspects of design coordination.

3. METHODOLOGY

This research is based on a sixteen month field study of design development and coordination meetings for the Centre for Interactive Research and Sustainability (CIRS) project (Figure 1). CIRS is a 58,000 square foot research facility that aspires to be the most innovative and high performance building in North America. The CIRS design coordination meetings were held weekly in the architects' office and typically included structural, electrical and mechanical consultants, the owner's representative, and construction manager's representatives.

Figure 1: Left; 3D renderings of the Centre for Interactive research on Sustainability (courtesy of Busby Perkins + Will), Right; typical setting of the meeting environment.

We conducted an ethnographic field study involving the observation of design coordination meetings, and analyzed our results using a grounded theory (Phelps et al., 2010) approach. The work practices of project teams were observed in the field and qualitative observational data about meeting processes was systematically collected in the form of observer notes, video footage and a few targeted interviews with participants. Instead of observing many meetings from different phases of projects, observations on pre-construction design coordination meetings were chosen. Over a sixteen month period, twenty-seven consultants' coordination meetings were attended in the architects' office. Each meeting took between one and two hours. During the observational study, researchers looked for inefficient meeting practices: situations where the meeting workflow was interrupted or situations where the observers thought that the meeting tasks could have been performed more easily or more efficiently. Team members' interactions with information artifacts were observed in order to better understand the use of these artifacts during meetings and their role in contributing to or mitigating bottlenecks. The interactions between meeting participants and their effect on the overall meeting process were also considered. Detailed notes were collected during each meeting, including the names of attendees, discussion topics, bottlenecks observed, and observations related to the decision making process. A document was prepared for each meeting using observer notes, notes on available artifacts, artifact use, observations about execution of meeting tasks, and interactions between meeting participants in as much detail as possible. The meeting agenda and meeting minutes (if available) were added to this information set. Instances of observed live interactions were noted with actual time and descriptive notes by the observer and later a snapshot of the corresponding recorded video frame was added in order to reflect the context during the meeting. Additional instances were observed from viewing of the videos. This way, informative and descriptive vignettes were created from each meeting. The vignettes included textual information and provide contextual clues for the reader about the specific bottleneck. Formal and informal interviews were conducted with the meeting participants in order to crosscheck our intuition about the causes of the observed bottlenecks. The analysis and coding of project meetings were performed according to conventions of grounded theory as defined in Phelps et al. (2010). Open coding, axial coding and selective coding were used sequentially to develop the proposed taxonomy of meeting bottlenecks. An open coding process was performed on the data set created from the meeting documents. This process resulted in a list of observed bottlenecks. Among the list of all observed bottlenecks single events were eliminated. During axial coding, similar bottlenecks were grouped, resulting in a set of bottleneck categories. After the selective coding, the taxonomy of design coordination bottlenecks was structured.

4. CASE STUDY RESULTS

The proposed taxonomy of design coordination bottlenecks in building design coordination meetings that we developed using the findings from the CIRS case study is represented in Table 1. The case study is representative of typical projects in the industry.

Table 1: Proposed paper-based, co-located meeting bottlenecks framework

People	Meeting Environment	Drawings	Interaction / Access	Information
• Group Composition • Group Dynamics • Availability	• Access to Design Information • Meeting Management	• Content • Symbols • Visualisation	• Visibility • Annotation • Remote Pointing • Navigation • Manipulation	• Exchange • Interdependencies • Availability

Figure 2 shows the breakdown of the 294 identified meeting bottleneck instances from data collected during the 27 co-located paper-based meetings. The largest number of bottlenecks observed in the analysis was of interaction/ access group of bottlenecks, followed by information, drawing, people and meeting environment groups of bottlenecks. When we look at the distribution of the bottlenecks in more detail, we see that visibility bottlenecks are the most observed meeting bottlenecks followed by remote pointing, content and information exchange bottlenecks. Parts of the taxonomy will be explained in detail in the following sections.

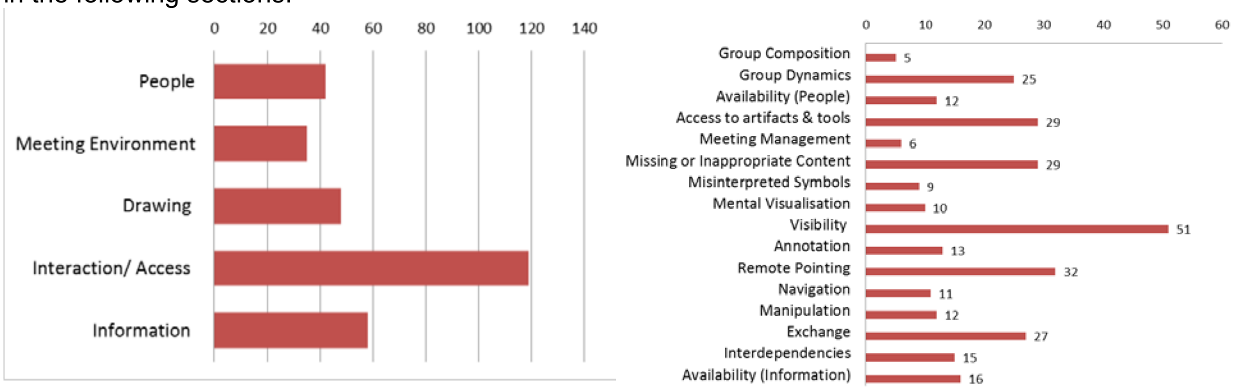

Figure 2: Distribution of observed meeting bottlenecks according to meeting bottlenecks categorisation.

4.1 People

4.1.1 Group Composition: The composition of a design team may change multiple times as the team players sometimes change throughout the project phases (Liston et al. 2001). When a team member changes, the knowledge about the evolution of the design may not be completely transferred to the successor. This creates breakdowns in the information flow between team members, and leads to iterations of coordination tasks like descriptive, explanative tasks. Throughout the CIRS design phases, team members like the project architect, mechanical consultant and owner's representative changed positions with people from the same organizations. The example below shows a captured conversation between the project architect and the new mechanical consultant who replaced a consultant from the same engineering firm. The new member of the team is not aware of and was not briefed about a previous discussion by his predecessor.

> Architect asks for an update about a part of the mechanical system that was discussed previously. Mechanical consultant apologizes for not having that information. Architect says "it's okay, you joined the team later during the design process, and we discussed this before you joined the team"

4.1.2 Group Dynamics: Meeting participants are often from various professional backgrounds, with different levels of experience, characteristics, responsibilities and authority. Sometimes a participant's approach to a coordination issue may be influenced by responsibility to his/her firm or a specific goal related to the individual's position in the project. This section covers bottlenecks that occur because of the clash between individual goals of meeting participants and the lack of a collaborative agreement on the project goals. The example below shows that team members have different concerns and goals about design process and the use of Building Information Modeling (BIM) and how individuals prioritize project goals differently.

> Architect mentions resynchronization of drawings for digital coordination. Owner's representative wants to know why they need the project models and expresses concerns about starting with Revit. Owner's representative: "Should we coordinate at own offices? It is going to be a big loss of time if everybody … What will we be looking at on the model during the meeting?" [Architect's concern is implementing a coordination process through model use. But the owner representative's main concern is speeding up the overall process and not spending time on trying to figure out requirements of this new process.]

4.1.3 Availability: This section covers bottlenecks related to not having the right group of people available in coordination meetings to make informed decisions. Sometimes people with the required information or knowledge are simply not present in the meetings to provide the necessary input on a discussion topic. There were two common reasons for this bottleneck type: (1) a team member who is a part of the regular meeting group was not available in a meeting, and (2) a person with the required knowledge and authority on a discussed topic is not included in the meeting. Availability bottlenecks caused delays in decision making or delays in getting required information. In the example below, the Construction Manager's (CM) representative is not present during the meeting to clarify a concern about the sequencing of construction. The discussion ends without a clear answer to the consultants' concerns.

> The building is going to be built in phases and the participants are not sure when the auditorium is planned to be built by the general contractor. Mechanical consultant has a concern that the ground source cooling system construction (proposed to be located underneath the auditorium space) would lengthen the construction time but architect doesn't think so, because he believes that the auditorium will be built last.

4.2 Meeting Environment

4.2.1 Access to Design Information: This section covers bottlenecks involving access to the large amount of project information that the design teams use during design and coordination meetings. Teams may need to access this information during any meeting, at any moment. Most of the time, it is difficult to know in advance which information will be needed. The observed design team used an online design and data management software (Autodesk Buzzsaw), but the technology was not used during the coordination meetings.

> Structural engineer is giving an update on glulam frame details. The consultant did not bring any detail drawings with him to the coordination meeting. The drawings are at the consultant's office. Architect goes to the white board and sketches the detail on the board.

4.2.2 Meeting Management: This section covers bottlenecks related to handling of the meeting process, including the facilitator's preferred meeting management style, emphasis on the agenda and minutes, inefficient use of meeting time as a result of digression from the main topics, and forming the agenda from issues that do not interest most people in the group. Garcia et al.'s (2004) study on how to manage meeting agendas indicates that often a substantial number of agenda items concern only a few people in the meeting group. We observed that meeting productivity was impaired in the absence of an experienced facilitator or a well prepared meeting agenda. During one of the observed meetings the senior project architect, who was the regular meeting facilitator, was not present in the meeting. During this meeting, the discussion often shifted from the main focus of coordination and participants spent more time on details that did not necessarily concern all participants.

4.3 Drawings

4.3.1 Content: This section covers bottlenecks related to the content of drawings used during design coordination. The content of a design drawing is limited based on its intended use and a consultant's drawing focuses only on information about a particular system's design. During evaluation of the design from different perspectives, participants end up using multiple drawings and/ or artifacts in order to effectively communicate design information with others. When participants need to use multiple representations to compare data from multiple drawings, they need to go through sets of printed documents in order to find the relevant information, and reconcile information from multiple related documents, which requires time.

The architect uses the physical model and the artist's rendering at the same time because rendering has the ability to represent the visual effect of the materials used on the façade. It is not possible to see these effects on the physical model. Meanwhile participants can observe more than one facade at once on the physical model and compare facade characteristics to one another. They then will refer to plan drawings to get an understanding of the space use.

4.3.2 Symbols: This section covers bottlenecks involving a failure to correctly understand or interpret representations on a consultant's drawing. Design drawings represent the consultants' design intent — they contain domain specific language and information. The representation of information on drawings may even differ from one design phase to another in the same domain. The following is an example for a bottleneck caused by the architect's representation of windows on the elevation drawings.

At the end of the meeting CM asks for clarification about components represented on architectural elevations. CM to architect: "Could you let me know which ones are the windows and which are the panels in drawing A301?" [It is hard to identify the panels and windows from the drawings and the information is required for a more accurate cost analysis.]

4.3.3 Visualization: This section covers bottlenecks related to drawings' incomplete ability to communicate design information; for example, not representing all component characteristics or system designs' interaction with other systems or components. Visualization of design information on paper drawings (especially on 2D drawings) have shortcomings that hinder communication. For instance, within 2D plan drawings, it is not easy to understand systems or components that are above a certain height. In the example below the project architect requires additional information from the mechanical consultant because the 2D design drawings do not visually represent 3D characteristics of the mechanical system components. Visualization bottlenecks were also observed when the meeting participants were examining an issue about a vertical component that extended across multiple floors.

"So the equipment is tall?" Architect is evaluating different options about a mechanical room layout. He is asking the mechanical consultant about the physical characteristics of mechanical system components. [3D characteristics of the equipment are not represented in the drawing. Participants have to mentally visualize the component in order to evaluate different layout options.]

4.4 Interaction/ Access

While design teams perform meeting tasks they use information artifacts such as drawings, documents and physical models. In order to perform meeting tasks efficiently, design teams need to be able to easily access and interact with these artifacts. Interaction/ access bottlenecks include remote pointing, annotation, navigation, visibility and manipulation bottlenecks related with the artifacts.

4.4.1 Remote Pointing: Observations in this study showed evidence that the lack of tools for remote pointing on digital and physical artifacts created interaction bottlenecks, which in return slowed down meeting processes and interrupted workflow. Participants did not take advantage of information artifacts that were available in the meeting room, just because they did not have instant access to the artifact or did not have the proper tools for remote interaction. Instead, they preferred longer verbal descriptions.

While the owner's representative is talking about an issue about the site and one of the neighbouring streets, he does not use the physical model which sits on a table in the room, simply because he does not have an efficient way to interact with the artifact; he would need to stand up to get closer to the model.

4.4.2 Annotation: During meetings, team members perform sketching, annotating, and note-taking activities on different information artifacts. Annotations are often used to clearly express an idea, propose a design change, and create meeting notes. Observations in this study showed that annotations, which are used often during meetings and can be very explanative, are often not used efficiently. Annotation bottlenecks were observed when participants were making annotations on physical and digital artifacts (which cannot be kept as a record if required), communicating an idea using sketches, note-taking, viewing and manipulating annotations of other people, keeping a record of these annotations, etc. The following example shows a need for personal annotations (in this case sketches) to be easily accessible and viewable instantly by other group members in order to solve problems faster:

While discussion continues on the drawing board, the architect is sketching a detail on his notepad, which will be used in a minute to help solve the discussed issue. If he could have used a common display to show his sketch remotely on this surface, he could have helped others solve the issue faster, and other participants would be able to view the explanative sketch much easier on the display rather than trying to see the sketch on a notepad.

4.4.3 Navigation: Navigation bottlenecks were observed when participants were searching for the most relevant data amongst different forms of information sets. During the meetings, consultants had to go through stick sets of drawings in order to find relevant drawings. The example below explains an instance where the architect navigates in a stick set. The architect had to move back and forth in the stick set during a discussion about mechanical system layout. In this case the actual navigation time takes virtually as long as the discussion itself. Often the participants preferred to bring smaller scale drawings so that it would be easier to navigate through pages and the drawings would take less space in the meeting environment. But this caused visibility problems when looking at detailed information on drawings.

The architect is going through different plan drawings to point out areas on floor plans while discussing space requirements for the supply and return for the cistern. He spends time finding the first related drawing page in the drawing set. Then he flips back and forth between the different plan drawings as he talks about the mechanical system routing.

4.4.4 Visibility: This section includes viewing problems (group viewing, individual viewing etc.) that were observed while the participants were working with paper drawings and documents, digital representations of information and physical models. During observed meetings, there were often times when team members had problems viewing artifacts. Visibility of information artifacts was noted as a bottleneck during this study since it was one of the most common observations. However, the effect of this problem was not usually noticeable from the workflow perspective. People were often observed having difficulty on viewing artifacts but most of the time they seemed comfortable with it.

Meeting participants often passed around drawings during discussions to have a better look at relevant information. Participants talk about the design as they view the drawing. However, not all participants have access to the drawing during the discussions. It is hard for the participants to view and interact with the artifact collaboratively at the same time.

4.4.5 Manipulation: Traditional 2D drawings do not allow many interactions that project teams need to perform during a meeting such as zooming in on a part of the drawing and getting quick measurements. Lack of such interactions can affect the efficiency of the team and hinder the effectiveness of information flow between participants. In the following example design team was using a small scale paper drawing. The plumbing consultant needed to zoom in on the problem area to be able to take an accurate measurement.

Plumbing consultant says, “I have to measure this distance. I have to blow this up,” as he is trying to answer architect’s question about the spacing of the sprinkler heads. [The architect's question remains unanswered since the required manipulation (zoom in and measure) cannot be done on paper drawings.]

4.5 Information

4.5.1 Exchange: A great amount of information is exchanged between consultants throughout a project. Design progresses fast, especially in the early design phases. The nature of design process makes seamless information exchange an important factor for a project to be successful. We observed numerous bottlenecks resulting from delays in information exchange between consultants. There was often a time lag between a design change and notification of other consultants about the change, which led to inefficiencies in the design process and created bottlenecks in information flow. In the following example, it turns out that CM’s budget calculations, which were discussed earlier in the meeting, were from an older version of the design drawings.

The design team is discussing the auditorium design. CM's representative: “the drawing that I am working with right now doesn’t have that detail.” [It turns out that the CM, who is working on the project's cost estimate (a very important aspect about the progress of the project), has not been working with the latest version of the design drawings. The CM was not informed about recent design changes.]

4.5.2 Interdependencies: Interdependency between the consultants’ design information were noted as one cause of inefficiency in decision making. Design decisions and discussions are multidimensional and interrelated with the decisions made by other consultants. Although discussion of interrelated items is considered as a natural part of problem solving, the observed issues were more about (a) not being able to move forward (or make a decision) because of complexity or the absence of information required, (b) moving away from a discussion topic that is in the meeting agenda, to a number of different topics that requires detail information or considers only specific members of the design coordination team. During the coordination meetings, consultants have to evaluate scenarios together to come up with a solution that works well with everyone’s design criteria. That is why discussion of a topic sometimes triggers other discussions.

The owner's representative explains a storage area requirement in the building. Topic of accessibility to the storage area comes up and the team evaluates the possibility of moving washrooms to the storage area. The solution also depends on other system designs. Dropping the washrooms might trigger problems with the plumbing. Washrooms can be below the utilities level from the street, but in this case pumps and extra mechanical equipment may be required. The discussion takes too long and the issue remains unresolved. Team decides that they need mechanical consultant’s approval or ideas about moving the washroom to the storage level and they move on to the next issue.

4.5.3 Availability: When information was not available during a meeting, the design team could not make informed decisions, issues remained unresolved, questions remained unanswered, and the design team moved on to the next topic on the meeting agenda without a final decision. We observed three main reasons for this bottleneck: (a) the required information was created, but was not available in the meeting, (b) more information was required to make a decision or (c) needed information was not created yet. In the following example, the discussion was about the size calculation of the emergency generator fuel tank. The team realizes that the required information was simply not available to make a final decision.

Q: “How long does it (the generator) have to run?”
Q: “Is it thirty minutes (until everybody is out) or does it have to run longer?”
Q: “Where does 'the generator has to be able to run for 12 hours' come from?”
[After discussing the same issue for about fifteen minutes the team understands that available information is not enough to make a decision on the subject. Additional information is required from consultants before making a final decision.]

4.5.4 Analysis: Project teams evaluate different design options throughout the evolution of a project, in an effort to find the best fit to achieve the project goals. We observed a lack of technological support during the evaluation of different design ideas or solutions. The analysis required by the team includes evaluating the effect of a proposed design option according to compliance with other parts of the design, cost, schedule, construction sequencing or code requirements. The following is an observation where a participant would like to know what the incremental cost of a design change would be.

Partnering consultant asks “what if” questions about the cost: “what if …… then what would be the incremented cost?” [There may not be a quick answer to these types of questions since further analyses and calculations have to be done before answering them.]

5. CONCLUSION

This paper described the results of a 16-month ethnographic field study that involved observation and analysis of twenty-seven design coordination meetings during the design development phase of a high performance institutional research building. We identified and characterized meeting bottlenecks in a framework that illustrates the nature of each bottleneck and the frequency of its occurrence. The taxonomy of design coordination meeting bottlenecks provides a more holistic characterization of meeting bottlenecks than what has previously been represented in the literature. This research studied the existing work practice of project teams in design coordination meetings. Our observations point out the need for improved information sharing amongst team members, new tools to help design team to be able to more easily and quickly understand and analyze design issues and options, and make informed decisions. During a meeting information artifacts should be accessible by all participants. Project teams need to be able to view information both publicly and in private to better understand and evaluate discussion topics. When an artefact is being used by a participant, other participants should still be able to view or be able to interact with the same, or the digital representation of the same artifact. Personal interaction with the artifact should not hinder other participants' interaction with the same information. Our hope is that by better understanding the meeting process and the bottlenecks observed, we can design technologies that provide better support for the unique needs of building design teams. In particular, technologies that enable better interaction with information artifacts, seamless exchange of data in meeting settings, and advanced visualization technologies for better communication and decision-making.

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