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Messy talk and clean technology: communication, problem-solving and collaboration using Building Information Modelling

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We studied the organizational practices around Building Information Modelling, or BIM, in inter-organizational collaborations among architects, engineers and construction professionals in order to theorize how communication supports technology adoption. Using ethnographic observation and one-on-one interviews with project participants, we observed five teams on three different commercial and institutional building projects that each collaborated over periods of 8–10 months. In this paper, we argue that the dynamic complexity of design and construction processes requires what we call 'messy talk'—conversations neither about topics on meeting agendas, nor on specified problems or specific queries for expertise. In messy talk interactions, AEC professionals contributed to innovation and project cohesion by raising and addressing issues not known by others. The communicative 'affordances and constraints' of BIM structured meeting conversations away from less structured, open-ending problem-solving and towards agenda-driven problem-solving around already identified problems. In other words, using BIM to make information exchange more efficient and effective worked only for certain tasks. We found BIM supports the exchange of explicit knowledge, but not necessarily informal, active and flexible conversations and exchange of tacit knowledge through messy talk. Although messy talk is perceived as more inefficient, it ultimately makes inter-organizational teams more effective.

Keywords: Building Information Modelling, communication, inter-organizational collaboration, temporary teams.

Introduction: the relationship between collaboration and Building Information Modelling

Increasing complexity in the building process requires an extensive array of design and construction specialists from diverse disciplines and multiple firms to work together in temporary teams. Common approaches for facilitating inter-organizational collaboration involve some combination of risk sharing, obtaining access to new technologies and markets, co-location and pooling complementary skills (Hagedoorn, 1983; Kogut, 1989; Kleinknecht and Reijnen, 1992; Eisenhardt and Schoonhoven, 1996; Harty, 2005). However, in the building sector, cultural and organizational boundaries tend to stifle communication, collaborative work and joint problem-solving even when contractual agreements try to encourage an environment of teamwork (Mitropoulos and Tatum, 2000; Cicmil and Marshall, 2005). In previous research, we found that disciplinary cultures and the norms of organization on construction projects play important roles in how communication practices contribute to a successful project. Where people working on a project have conflicting obligations, the conflict often impedes successful organizational collaboration. (Dossick *et al.*, 2009; Dossick and Neff, 2010). Still, supporting collaboration across organizational boundaries remains one of the key arguments for Building Information Modelling (BIM) (CURT, 2004; American Institute of Architects, 2006; Eastman *et al.*, 2008; Smith and Tardif, 2009). While teams may be more satisfied with results when digital tools are introduced to help coordination, 'considerable mutual adjustment' is often required to make

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technology adoption successful in inter-organizational collaborations (Orlikowski, 2000; Liston *et al.*, 2007; Taylor, 2007). Tools—even those intended and designed for the purpose—are not sufficient for supporting collaboration.

The predominant themes in the academic and professional literature on BIM concern how technology can support collaboration, focusing overwhelmingly on technological aspects of collaboration. Issues concerning the creation, exchange and management of data; the creation of naming conventions; shared geometries and scales and software interoperability are important for getting teams to work in shared computing environments (Taylor, 2007; Ku *et al.*, 2008; Smith and Tardif, 2009). Taylor (2007) found that through the co-creation of a BIM model 'disparate' design and construction firms 'more clearly articulate their knowledge of constructability issues'. While BIM tools excel at documenting and representing design and construction decisions and conflicts, teams most often adopt BIM to help in complex problem-solving; for example, BIM is currently used in mechanical, electrical and plumbing (MEP) coordination for precisely this reason. However, much of the research to date has focused more on the technical requirements of BIM, and within industry work is currently underway to define new standards for information exchange as it relates to BIM technologies (Smith and Tardif, 2009). Less is known about the managerial and leadership decisions needed and the communication practices required to make BIM a useful tool for collaboration on complex problems.

In this paper, we turn our attention to the dialogue and conversations that constitute collaboration, especially those in technologically supported environments. We find that BIM tools are useful for project documentation, problem discovery and decisions pertaining to object-oriented design and construction. However, as currently employed, BIM tools are often at odds with the dynamic and 'messy' activities needed to support problem-solving dialogue. Figure 1 illustrates the juxtaposition between a 'messy' whiteboard discussion and a formal somewhat static BIM projection.

In the settings that we studied, BIM was used across organizational boundaries, including interdisciplinary scope coordination (e.g. MEP coordination), as well as for the vertical integration of information exchange within one design and construction discipline such as steel design, fabrication and erection. We find that in these contexts BIM does not replace talk for problem-solving or finding optimal solutions because these solutions are distributed across disciplinary boundaries and require the exchange and discovery of tacit knowledge.

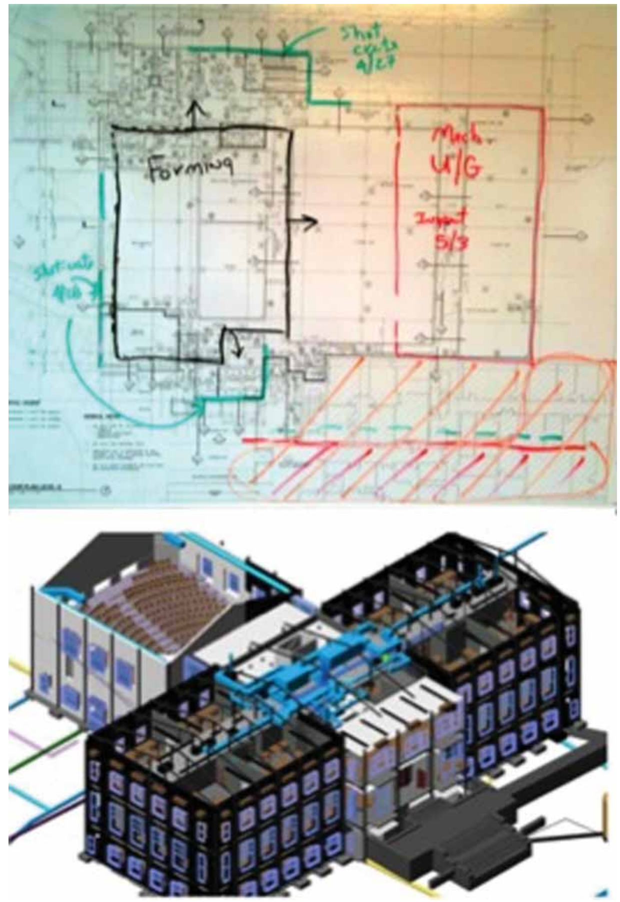

Figure 1 Examples of whiteboard 2D plan with sketch and a 3D BIM

Our paper proceeds as follows. First, we introduce the setting and methods, define the concept of 'messy talk' and discuss the 'clean' characteristics of BIM technology. Then, we explore the tensions between messy talk and clean technology along three dimensions: passivity–activity, formality–informality and flexibility–inflexibility. In this analysis, BIM supports problem definition and explicit knowledge creation, but not problem-solving and tacit knowledge exchange.

Defining messy talk

Collaboration is inherently messy. We define *messy talk* as the interstitial dialogue between and after formally organized agenda items. Messy talk is similar to brainstorming because it supports shared knowledge creation. Brainstorming, as defined in the literature, is planned and anticipated, supports organizational memory, provides skill variety for designers, creates an inquisitive, knowledge-based environment and rewards technical skill (Sutton and Hargadon, 1996). Unlike brainstorming, messy talk is unplanned, unforeseen and unanticipated, related to what others have termed the 'unexpected discoveries' that are made when drawings are jointly viewed and discovered (Suwa *et al.*, 2000).

We use the concepts of explicit and tacit knowledge to explore teamwork task types and how BIM tools support or hinder communication, collaborative learning, knowledge creation and exchange. Explicit knowledge ('the what') is the knowledge that can be documented (Carrillo and Chinowsky, 2006), such as the building components; these are typically captured in BIM, technical models, drawings and specifications. Tacit knowledge ('the why') is the knowledge that people acquire from experience (Carrillo and Chinowsky, 2006; Whyte *et al.*, 2008). This includes, for example, the reasoning behind the selection of a steel structure (as opposed to concrete or wood); some of this information may be recorded haphazardly in meeting minutes, engineering analysis reports and design memos, but as described by Whyte *et al.* (2008), much of this information is held only in the brains of the individuals who made these decisions.

> [Through] interactions between people and objects … the meaning of words, actions, situations and material artefacts are negotiated. Learning takes the form of a 'conversation with materials', involving interactions with an object that may itself be changed and reconfigured as part of this knowledge work, and it also involves story-telling and conversation between people and groups. It is through a broad set of social practices that meanings are negotiated and knowledge becomes constructed and validated. From this perspective, knowledge is emergent, deeply grounded in practice, and not something that can be fully captured, codified and transferred. (Whyte *et al.*, 2008)

As Whyte *et al.* (2008) argued, tacit and explicit knowledge are inseparable and only understood as 'emergent, developed through interaction between people and objects' (p. 74). Consequently, for the practitioner who creates visualizations or models, these hold much more information for the practitioner than when given to others. Those who receive a drawing or a model reinterpret that drawing and model through their own domain lens, their role on the project and their expertise.

Messy talk, we argue, is especially important in situations when it is not clear who needs to know what, and when issues are raised with the preface, 'That reminds me'. It is the emergent contextual mutual discovery of the issues that may impact others or have unintended, unforeseen consequences for the project. Conversational references or visual tools prompt project participants to bring up a subject or issue that they feel is important for the problem at hand or a messy talk item may be information that the team needs for future work. However, for messy talk to occur, a team needs to be organized and ready to engage in it.

Defining clean technology

Architects, engineers, fabricators and builders are using BIM tools to document, identify, exchange, calculate, analyse and see information about the building. These new computer tools ease the process of communicating and exchanging technical specifics such as geometry, reference points, material type and quantities between different project participants and are very good for documentation, data exchange and data management (Ku *et al.*, 2008). In this time of technological transition, project participants must establish practices and expectations local to the project related to the types of BIM data that are generated and exchanged.

Clean technology refers to the explicit processes and standards required for sharing digital information as well as to the idea that technological exchange is somehow more reliable, less fallible and more precise than human communication that is not mediated through digital communication tools. BIM tools rely on clear definitions, shared environments and prescribed boundaries. In order to share within a technical environment, communication needs to adhere to clear, shared rules and understandings. Technical solutions proposed by advocates for BIM promise to replace inefficiencies in part through creating shared knowledge repositories that are readily accessible and legible to people in multiple disciplines with multiple professional perspectives on the design and building process.

However, the 'cleanness' of the technical solutions of BIM may not support what is needed for talk, conversation and problem-solving. Explicitly visualized geometries might leave little room for the interpretive flexibility required for crossing inter-organizational knowledge boundaries (Neff *et al.*, 2010). Having some ambiguity 'may be useful for some tasks, where we want representations that help us move between focused reasoning and free association' (Whyte *et al.*, 2008). Modelling a building system with accuracy might take more time and be less efficient for design generation than 'messier' talk, sketching or drawing, because once inscribed within the model, certain pathways or potential solutions may be closed. Visual materials, whether 2D printed drawings or 3D computer screen images, cue project participants to mention issues to others and start problem-solving discussions that were neither planned nor scheduled. Could the same technical precision that makes BIM such a useful mechanism for documenting explicit information inhibit the process for generating and sharing active, informal, flexible and messy tacit knowledge?

Setting and method: ethnography and grounded theory

We chose a qualitative research design to build theory based on observed practices of people implementing change within the AEC industry. The 'grounded theory' method that we describe below is well suited for generating theories that explain the dynamics and processes in multiple settings, not just those observed for this research. This method allows researchers to develop a rich picture of social practices and is ideally suited for observing culture, communication and values, especially in workplace settings where these may be changing or in conflict.

We conducted participant observation among five teams on three different building projects (Table 1). Each team collaborated over periods of at least 8–10 months for over 500 field hours of work. For these building projects—Hill Medical, Valley High Rise and Campus Lab—we observed the weekly detailed design meetings of the MEP subcontractors and the general contractor, in which they jointly coordinated the design of their respective systems. Additionally, for Campus Lab, we observed meetings of the architect and the engineering and other design consultants during the conceptual and detailed design phases and the owner, architect and general contractor meetings that began in the pre-construction stage. We observed these meetings for how participants used technology to communicate with one another, how collaborative conversations were initiated and maintained and how problems were identified, discussed and resolved. We wrote detailed field notes as soon as feasible after each observation and meeting; the notes comprise nearly 150,000 words over the three building projects. We then compared these field notes using an iterative coding scheme based on the methods of 'grounded theory' development (Glaser and Strauss, 1967; Strauss and Corbin, 1990) using Altas.ti qualitative coding software.

We generated a set of conceptual categories over the period of three years during which we observed all of the projects, and these conceptual categories were 'respondent checked' through one-on-one interviews with team participants to establish that we were capturing the dynamics that the participants also observed. Consistent with grounded theory methodology, these categories began at a general level (e.g. collaboration), then cohered into more specified conceptual categories (e.g. collaboration using plan, collaboration using model and passivity in communication). We diverged from grounded theory's method of strictly separating the phases of qualitative data collection and analysis. Instead, we used accepted methods of empirical field research by writing in-depth analytical memos, having regular case analysis meetings of all researchers working in the field and creating cross-case concept

Table 1 Summary of research engagement with five temporary teams

	Hill Medical MEP	Valley High Rise MEP	Campus Lab MEP	Campus Lab architect/ consultants	Campus Lab owner/ architect/contractor
Methods					
Length of observation	9 months	9 months	8 months	10 months	8 months
Meeting participants	6–9	7–12	10–15	6–14	8–12
Participant interviews	5	4	5	6	3[a]
Field note word count (approx.)	21,700	43,500	18,000	53,500	9500
Characteristics					
BIM used	Yes	Yes	Yes	No	No
Meeting style	Face-to-face, weekly	Face-to-face, weekly	Face-to-face, virtual, weekly	Face-to-face, weekly	Face-to-face, weekly
Meeting agenda	Driven by 'clashes'	Driven by 'clashes'	Driven by 'clashes', GC agenda	Architect agenda, loosely followed	GC agenda, closely followed
Visual communication	BIM model projection	BIM model projection	BIM projection, online documents, paper, sketching	Paper, posters, sketching	Paper, sketching

[a]Observations and interviews ongoing.

matrices while continuing to collect data (Miles and Huberman, 1994). By the mid-point of our observations of the fifth team we studied, the Campus Lab MEP coordination, the researchers had confidence that 'theoretical saturation' had been reached and findings echoed the topics, concerns and conceptual samples from the four previous teams.

We verified the conceptual categories through comparison with the general themes articulated in data gathered from over 70 independent interviews of architects, engineers and builders across the USA on how the transition to new technology influences communication and collaboration. These data allow us to confirm that the practices that we observed within our three specific cases reflect the concerns and issues of our interview respondents and that our observations resonate with the articulated challenges facing such teams more generally. Below, we present findings based on our three years of field research with five different teams and on the data from our interviews across the USA.

Findings: encouraging and discouraging knowledge sharing

Our data suggest that collaborative work involving talk, conversation and problem-solving is not necessarily enhanced by BIM. We have observed a paradox in how BIM supports collaborative work: BIM excels at helping people *find* problems, but does not support the dialogue needed to *solve* many problems encountered in complex design and construction projects. This creates tensions when BIM is introduced in the process of design and construction. BIM technology makes problems more explicit in that teams can see potential constructability or design issues, yet our research shows significant differences in the organizational environments varied by how well collaborative knowledge generation or *messy talk* was supported by the organizational process around BIM. To show how messy talk unfolds and how clean technology is sometimes at odds with this unfolding, we organize the discussion around three dimensions of communication:

(1) formality–informality
(2) passivity–activity
(3) inflexibility–flexibility

Formality refers to the function of documents and artefacts as technologies of accountability and authority within organizations—demonstrating the role of documents supporting the organizational hierarchy, controlling information and communication flows and producing distributed authority in organizational contexts (Marvin, 1987; Yates, 1989; Benoit-Barné and Cooren, 2009). *Informality* refers to the ability of documents and visual artefacts to support talk in 'communities of conversationalists' (Taylor and Van Every, 2000, p. 32), especially around information that may be less precise or incomplete. We use the terms *passivity* and *activity* to refer to the ways in which people interact with information, actively or not. For example, routine ways that problems are logged and shared among project team members may supplant more direct and active talk and conversation around those problems. While a document may *passively* shape, structure and even direct organizational activity (Cooren, 2004), its particular agency is not necessarily pre-determined. Fiore-Silfvast *et al.* (2011) found many instances in which people had to *actively* work to change a document or document pathway to activate its usefulness for collaboration. *Flexibility* refers to visual artefacts such as sketches which can be messed with—those 'which are touched, pointed to, and annotated during the meeting' (Whyte *et al.*, 2008, p. 85; see also Henderson, 1999). *Inflexibility* refers to artefacts around which teams tend to discuss future actions but not necessarily use to actively co-create knowledge together, as has been shown with PowerPoint (Whyte *et al.*, 2008) and certain databases (Henderson, 1999).

These dimensions allow us to examine when and how formal, passive and often inflexible clean technology, collides with informal, active and flexible messy talk. What we call messy talk brings innovative connections together, thereby supporting collaborative problem-solving. As used currently in practice, BIM instead fosters formal and passive communication of knowledge and inflexible visual communication and does not support messy talk, which arguably leads to innovation. The technical 'affordances' and 'constraints' of BIM modelling foster formal communication, passive knowledge sharing and inflexible visual communication, but these in turn do not help support messy collaborative conversations that require informal, active and flexible visual media. Our analysis provides insights into how the social practices around BIM tools could better support collaborative, problem-solving communication despite the constraints of current BIM technologies.

Formal and informal communication

We found a tension between formal documentation and the dynamic needs for informal dialogue throughout our ethnography and our interviews. In many settings of design and construction, the need to work collaboratively—sketching, annotating, brainstorming and problem-solving—was in direct conflict with the need to document, creating a paper trail with letters, memos and drawings (Table 2). In an environment

Table 2 Axes of communication dimensions

Clean technology				Messy talk				
Formality		Passivity	Inflexibility	Informality	Activity		Flexibility	
Drawing,3D models, Contracts	Noticing model changes	Revising and reworking around changes without discussion	Projected BIM models during without meetings	Sketches, Annotations	Discussing model changes	Hearing implications of changes	Whiteboard plan	Sketching on sign off documents

that relies on written documentation for those conversations, one project manager expressed the need for talk in contrast to electronic communications:

> [I]f it isn't [in] an email, it's not real. If you have a face-to-face conversation, you need to document it in an email, or we have to follow it up in some kind of communication, but we can't rely upon verbal communication anymore. (G091201_BFS)

This tension between the need for the quick but messy verbal communication and the need for procedural and legal documentation of decisions and discussion is pervasive in the dynamic organization of a building in the making. One example occurred during the MEP sign-off for a basement level of Campus Lab: the electrical subcontractor marked with his pen on the BIM-generated but printed 'sign off' document set, clouding an issue that had just come up in the meeting. He sketched on the sign-off documents as a visual aid for making his point. One of the project managers joked, 'We were going to sign off on that', noting that the drawing itself was rendered useless for formal documentation of their joint decisions by the act of sketching and messy talk. The bubble drawn on the paper made the material the messy talk of the organization, which was then in direct conflict with the organization's need to formally document the decisions. The BIM process succeeded in enabling formal documentation of completed inter-organizational decisions; but project personnel could subvert the formality of BIM and printed document to support messy talk when decisions had yet to be finalized.

In our teams, we repeatedly observed this tension between the clear-cut technological solutions such as BIM and the need for less structured, 'messier' talk around problem-solving and decision-making. This is illustrated by a comment from the assistant superintendent, who was in charge of a web-based BIM MEP coordination for Campus Lab. He complained about the absence of a dynamic conversation by saying, 'For the meeting minutes, I need dialogue'. In an effort to make the process more clean and efficient, individuals called in from their own offices and saw a shared web-based projection of the BIM on their computer monitors. They did not have eye contact as they only heard each other's voices over the phone. This superintendent's concern was that while meeting participants were identifying problems on the screen, they were not discussing them. This suggests that the ways in which they were approaching mutual problem-solving was not working to generate talk around those problems. Additionally, the team members tended to go through their own lists of issues that they had identified before the meeting. The clean technology of a shared model did not provide them with a medium for free form discussion, and in their agenda to go through the BIM-generated list of system clashes, they often missed opportunities to think about optimizing systems or to jointly optimize decisions around the project. Over the phone and through their computer images, they were not able to huddle, sketch or otherwise share more informal collaborative talk. They were limited to addressing the clear list of clashes shown by the computer and as the superintendent pointed out, they were not fully discussing these problems in the web-based setting.

Passive and active communication

In our interviews and interactions with industry professionals, one common assumption of BIM was that knowledge can be passively communicated among the team, bypassing talk with cleanly articulated technical specifications about the building. As one architect said,

> In some respects the modelling *forces* communication. You can say it enhances, but I like to say forces, because you might think, 'Oh, I'm going to have to tell so-and-so I moved this column,' and walk over there and tell them, but if so-and-so is sitting over there and all of a sudden they see in the model they're working on that the column has moved. . . it's right there in front of them, they see it. And it will prompt them to ask you, 'Hey, you moved the column?' So there's a level of just managing all this information internally. (A071024)

In many respects, the 'forced', but efficient communication in BIM that this architect discussed is actually a more passive dialogue. The architect quoted above felt that BIM replaces less efficient talk and that talk is then redundant when someone else can just see the change in the model, assuming that these changes force someone else to notice. Rather than actively discussing or mentioning changes, the assumption is that someone who needs that information will take notice. These assumptions are encoded into a vision of practices around BIM, in which teams share information in real time, albeit passively and thus an opportunity for conversation around decisions and problems is missed. This implies that prior to BIM, the architect quoted here would have had to talk to others in the team to tell them about the column; but as he articulates here, with BIM the technical information exchange is passive through data transfer that eliminates the need to talk. In other words, the clean technical solution has supplanted messy talk.

However, in our observations and interviews, most design changes precipitated messy talk. For example, when an architect introduced a change to the design, there was often a long and technically complex discussion about the ramifications of those changes. The implications to structural, mechanical, electrical, architectural, acoustical and construction disciplines were compared and analysed during the messy talk of the team meetings. Moving shafts or changing ceiling heights, corridor widths and room arrangements all had significant multi-disciplinary ramifications that the teams discussed and resolved. No single discipline was solely optimized, but through messy talk the ultimate design decisions were a blend and balance between the disciplinary constraints. The superintendent for the general contractor on Campus Lab used this approach when he asked during an MEP meeting about what the team should be thinking about in order to optimize the project or prevent future issues during a potential, but not yet approved phase expansion of the building project. The messy talk process yielded a simple but powerful solution for the future problem of connecting the de-ionized water systems in the two phases of the project—a problem that technically did not yet exist, but whose solution most efficiently implemented during the building's first phase. Relying on known problems to drive the agenda, as the BIM technical and social process encourages, does not necessarily lead to active conversation around solutions.

Arguably, messy talk is not needed for every point of data exchange. Which tool and strategy is 'best' for the task, tech or talk, depends on which tasks are needed. Passive exchanges support documentation and analysis, while messier exchanges with dialogue support collaborative problem-solving and optimization of a collection of building systems, when a team may need to ask what are the ramifications of moving this column. We have observed that the move to more efficient processes supported by technologies can remove the sites for messy talk to occur. As designers and builders re-engineer the organizational processes around BIM technologies, they need to consider the need for both clean data exchange and messier human interactions.

Flexible and inflexible visual communication

Since BIM models make explicit visual 3D geometries, our teams used models best as a means to get people to quickly understand new problems, but such use did not necessarily generate new ideas about solutions to these problems. In our observations, more flexible visual communication—media such as paper and white boards that are easily 'messed with'—better supported joint problem-solving. For example, in a coordination meeting, after looking at a drawing spread out on the table, one participant said with seemingly no lead in that everyone should keep in mind a particular issue with the edge condition of the suspended ceiling and quickly sketched on a white board four simple lines to depict a tall edge and a gap. This stimulated further conversation around solutions and proposed actions from various team members. As this illustrates, to encourage dynamic collaboration and messy talk, the teams we observed used representations and technologies that are flexible and support activities such as sketching, editing and erasing. Formal BIM projections or printed drawings could spark a free associative idea related to a problem that the team might encounter, but the subsequent discussion and problem-solving was supported through drawing, sketching and modifying the existing view quickly and informally.

Another example illustrates the juxtaposition of a problem discovered and communicated through BIM, yet solved with quick informal sketching on a white board and inter-organizational messy talk. On Campus Lab, the architect and electrical superintendent started up a conversation after the formal MEP coordination meeting had adjourned. Based on the BIM model they have seen earlier in the meeting and related electrical interference analysis from the engineer, the problem was clear to both parties. To solve the problem, they turned to the whiteboard, and with a black marker, the electrical superintendent sketched a rough outline of the building foundation, adding in blue marker a possible alternative location for the duct bank, thereby removing it from the overcrowded corridor. As they discussed possible solutions, they pointed to the blue lines and talked about where the conduit would run, what shielding would be required and where the pipe would 'come up' from the ground after snaking through the foundation. After 5 min of discussion, the architect suggested running the duct bank along the west side with the current underground utility construction. After a flurry of conversation about what it would take to add this new scope to current construction activities that were happening in the next few days (including a delay of two to three days to the critical path), the team decided the west side of the building is the 'right thing to do for the project'. Upon reflection, the electrical superintendent said, 'I don't know why I didn't think about that … sometimes we have blinders on. I didn't think about the west side'. To which the architect replied, 'That's why it's great to talk it through and get multiple people thinking about it'. The problem was clearer for team members to discover and see in the BIM model, but project participants turned to more flexible visual aids and messy talk to arrive at a solution. Herein lies the paradox: while BIM tools help teams to 'see' the problem and articulate the issues to others, they seem to stifle the messy talk needed for problem-solving and exclude quickly sketched adaptations for proposing solutions.

In all of the teams, we observed a tight coupling between the flexibility of the visual representations and the development of knowledge in the collaborative dialogue. When the visual representations were flexible enough to allow quick sketches and outlines of potential solutions—the kind of sketching and outlining that team members perform using white board, paper or on the drawings themselves—the project participants engaged in messy talk that was characterized by project participants all proposing solutions and then reflecting on the ramifications of the proposed solution from the perspective of their domain expertise. However, when the visual representations were less flexible, i.e. a consolidated model projected on a screen, the project participants would identify issues, but would often stop short of problem-solving in the meeting, and instead tabled the problem for solution and resolution outside of the meeting. In fact, there would often be problem-solving conversations after the formal meeting was completed and the projector was turned off. As the formal meeting was adjourned, some project participants would huddle around paper drawings, scraps of paper or white boards while sketching problem-solving issues that were discovered or introduced earlier in the *official* BIM meeting. We conclude from these observations that while BIM makes explicit knowledge of 'the problem' more easily found, visualized and communicated, the process of resolving that conflict is not supported by the visualization in terms of the messy talk often required for problem-solving dialogue.

Discussion and conclusion: building in the making and the implications for BIM adoption

Messy talk is a mechanism for communicating tacit knowledge in complex projects where information creation, dissemination and control are distributed across multiple, disparate project participants. The need for messy talk is particularly acute in design and construction projects. Such projects are dynamic organizations of *building in the making*, where the organization is itself being created while the building is being made. This characterization of construction projects has been called a *becoming* ontology (as opposed to being) that 'privileges activity over substance, process over product and novelty over continuity' (Cicmil and Marshall, 2005). Consequently, organizations are not stable, but in a state of expansion or contraction—parts of the organization are in a state of being created or demobilized at any point in time. Temporary team members come and go according to the needs of the project, their scopes of work or their company's resource management strategies (Dossick and Neff, 2010). The work that these temporary teams do is characterized by 'intersubjective conversation' and 'joint action', where new knowledge and collaborative learning are needed (Cicmil and Marshall, 2005). In this state of *becoming*, project participants rely upon standards of practice and industrial history to guide their expectations and interactions with others on the team; our field work confirms the findings of others in the observation of a dynamic and flexible environment where protocols of interaction are emergent and 'contextually mediated' (Whyte *et al.*, 2008). As Suwa *et al.* (2000, p. 539) put it, 'a design process progresses in such a way that the problem-space and the solution-space co-evolve'. The conversations between architects, engineers, owners and builders are less about briefings and more about problem-solving (Ewenstein and Whyte, 2007).

There is a predominate focus within the literature on the technical, logistical and legal issues of interoperability, data exchange and model ownership. In these —and many other—conceptualizations of the BIM process, efficient technological solutions are posited as opposed to direct talk and dialogue and often implied to somehow effortlessly replace more direct communication. Based on our observations and analysis, we argue that meaningful teamwork across organizational divisions is characterized as much by dialogue as data exchange and as a temporary team defines collaborative processes, the choice between tech or talk is driven by the task and knowledge types. As designers and builders seek to be more efficient in their work, teams also need to maintain or enhance their abilities to be effective which may require sites for messy talk as well as more formal technological coordination.

The work done in the space of *becoming* is characterized by continuously changing information, knowledge creation, documentation and exchange. Until decisions are finalized, they are neither clean nor well ordered. The knowledge tools needed for this work need to be robust enough to capture, document and communicate the technical details while being flexible enough to accommodate the dynamic *becoming* environment where messy talk and change predominates. Designers will use drawings as a holding ground for later decisions (Ewenstein and Whyte, 2007), and in fact, many of the means and methods decisions are left for the construction project participants to develop outside of the formal drawing and specification set. In this way, plans are the visual representations that structure team discussions (Taylor, 2007). This separation between building as designed in the formal drawings and building as built by the contractor creates a dynamic *becoming* ontology that requires joint action and conversation (Cicmil and Marshall, 2005). Visual representations used to express the data of a construction project may both sustain and hamper communication (Ewenstein and Whyte, 2007).

Current BIM tools are very good for storing, displaying and exchanging explicit knowledge, but BIM does not support the why (e.g. design choices such as the logic behind the building form or the building's orientation on the site) and has as yet limited capabilities for supporting the how—the tacit knowledge of how a building is built. Consequently, BIM technology cannot replace the need for messy talk and the clean BIM technologies cannot replace or be a substitute for the messiness that is found within the multidimensional network of boundaries between the disciplines in design and construction. This in no way diminishes the powerful benefits of data exchange between designers, fabricators and builders. With BIM, problems are more quickly identified and are identified earlier in the design and construction process. BIM technologies make the design, fabrication and construction process more efficient in terms of data exchange and communication of problems or issues between the project participants, but there is work to be done around how project participants conduct needed dialogue about the problems and solutions. We have found that BIM representations do not necessarily make the process of finding a solution more efficient or effective. Finding a solution requires a messy talk process that is supported by flexible, active and informal artefacts—artefacts upon which people draw, write or otherwise modify.

Some of the subjects of our observations and interviews have tried to counteract the inflexible characteristic of projected BIM artefacts and enable messy talk by creating ways to sketch on top of the model images, either by projecting the model onto a SmartBoard, white board or computer tablet for flexible sketching and team discussion similar to the way that designers traditionally use tracing paper to enable sketching on top of more formal paper drawings and renderings. This clean tech versus messy talk means that some are trying to 'draw' on the technology, projecting the model in that still enables sketching and scribbling. Could different visualizations support messy talk differently, inspiring conversation topics in different ways, and for different ends? How can we use technologies to help organize and document yet resolve and optimize the multivariate multidisciplinary knowledge work that characterizes design and construction?

From this analysis, we conclude that the tool, strategy or medium that is 'best' for a task depends on the types of knowledge required. In our observations, problem-solving conversations around optimization required messy talk. In all three cases, the MEP teams were able to create error free models—working through the clash detection tools, but were these systems optimized for installation and building performance? In its current configuration, the 'clean tech' of BIM technologies facilitates more efficient knowledge capture, documentation and communication. However, to make some tasks more effective organizations need sites for the fuzziness of free association and the juxtaposition of seemingly unrelated things to generate new ideas and innovation or collective problem-solving that the current BIM interfaces do not provide. In temporary inter-organizational teams, distinct project roles and disciplinary lenses necessitate that project participants *see* the visual representations used to convey explicit knowledge in design and construction projects differently. The intersection of scope, constraints, constructability and design intent is often unanticipated, and it is only through the experience of messy talk that project participants realize that tacit knowledge needs to be shared. For the academic literature, our aim for proposing a theory of messy talk is less about the juxtaposition of social practices with their associated clean technologies. Rather, going forward, we see possibilities for this messy talk-clean tech divide as a theoretical tool for describing and analysing activities and practices along a spectrum and how they support collaborative problem-solving talk. Questions remain as to when we need messy talk and for what types of tasks. While messy talk may seem inefficient at the moment, it is clearly effective for the long-term optimization of complex problem-solving in inter-organizational teams.

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