Working Paper Proceedings

Engineering Project Organization Conference
Devil's Thumb Ranch, Colorado
July 29-31, 2014

Interpretive Flexibility and the Price of Documentation

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INTERPRETIVE FLEXIBILITY AND THE PRICE OF DOCUMENTATION

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ABSTRACT

Design and construction are rooted in layers of historical work practices that enable temporary teams of experts to quickly establish collaborative routines. However, work practices, drawing sets and written specifications that functioned well in the 2D environment may constrain teams working in 3D, and shape the ways they generate and discuss alternative solutions to problem. In this paper we present a model that allows for the analysis of the dimensions of interpretive flexibility, malleability, and documentation across the project process. We use qualitative ethnographic observations of three different building projects using BIM over a five-year period and 70 interviews of architects, engineers and builders across the USA. For the experts on these teams, documents with "interpretive flexibility," the degree to which documents can be read in multiple settings, can be generative, helping people "see" creative solutions to design problems within such documents. However, interpretive flexibility is also a liability at other points in the construction process, because of the possibility for multiple interpretations to cause confusion and costly rework. Three-dimensional models and data support collaborative conversations that are good for the discovery of problems, but the technology is no replacement for dialog amongst team members. We find that interpretive flexibility is reduced by 3D, and this reduces the ability for teams to generate solutions to discovered problems. As a basis for issue and conflict discovery, BIM acts as a site for conversation, but stops short of supporting exchanges around solution generation. Once design and construction teams develop solutions and alternatives, BIM then serves another useful role in helping to test and explore these solutions. In this way, BIM-based information exchange does not replace the need for expert interaction on design and construction projects, but enhances these interactions.

KEYWORDS: Building Information Modeling, Integrated Project Delivery, Collaboration, Communication

INTRODUCTION: TECHNOLOGY MISALIGNMENTS WITH TEAM ROUTINES & PRACTICES

Contemporary commercial buildings are large, complex systems that require an equally complex array of disciplines to design and build them. Norms of design and construction work practices enable temporary teams of experts to come quickly together (Neff, et.al. 2009). In this context, the introduction of Building Information Modeling (BIM) in the Architecture, Engineering and Construction (AEC) industry enhanced some existing work practices and fit with some project routines. However, BIM is misaligned with many of the routines and practices common on large-scale projects. At the industry network level, Taylor and Levitt (2007) identified misalignments between the BIM technology and the allocation of work in the US

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market as a barrier for successful BIM usage. They found that in Finland, where design firms create both the design documents and the shop drawing details, BIM technology adoption was more rapid than in the US market where this work is allocated across a multitude of firms, designers and builders.

In our study, we found a disparity in adoption between designers (architects and engineers) and builders. While builders adopted BIM to create detailed coordination models, we found designers reluctant to adopt these tools. In this paper we juxtapose the concept of level of development from the BIM literature with the notion of interpretive flexibility. This helps us analyze the ways that teams need to use documentation. While the construction phase of a project benefited from BIM which decreased the interpretive flexibility of project documents, the design teams struggled with BIM tools that presented higher levels of detail than matched the scope of the choices designers needed to make. This may explain why the US industry experienced relative ease in the adoption of BIM tools for construction, while adoption in the design phase by architects and engineers was slower.

TOOLS AND DESIGN PROCESSES

Design methods have gained some popularity in the business and management literature, as ways to structure teamwork that co-produces new knowledge and creates sites and spaces for generative work (Martin 2009). The complex interdisciplinary work of building design and construction can expose the importance of the form and function, (e.g. the affordances) of the documents teams use to co-generate new knowledge. The design process is iterative and cycles through Problem Definition – Identify Choices – Testing and experimenting with these alternatives to evaluate their viability to solve the identified problem. In looking at the schematic architectural design process, Suwa et al. (2000) found that iterations are swift and that problems and solutions co-evolve. As the design process starts, the choice field is wide open. Much of the work is focused on the problem definition (e.g., the development of the “Program”) and an exploration about what the users want to space to do alongside the design development around what types of spaces could meet or exceed these criteria. In early design, the scope of the issues are large, while the documents are at a low level of detail, intentionally abstract. As design teams work through this iterative process, they use malleable documentation tools to explore both the problem definitions as well as test and explore solution alternatives. Whyte et al. (2008) found that in an architecture firm’s “design decisions were deliberately delayed through the use of sketchier, less precise, media allowing the various designers time to effectively make sense of the unstructured problem” (pp 82). Suwa et al. (2000) found that “designing is a situated act; designers invent design issues or requirements in a way situated in the environment in which they design.” (pg 539)

As the design develops, design problems and solutions evolves into finer levels of detail, as the designers ask more and more specific questions and refined level of detail. Moving from choices about building mass, to structural systems selection, to connection details and wall finishes. The design process (problem – choices – testing) is repeated over and over again throughout the project lifecycle. As experts join the team, they work through problem definition, choice generation, and testing. A choice then is documented and defines the downstream constraints of the next design problems. Once a choice is selected, this solution is then codified in a document (model, drawing, narrative and/or specification), which is then used in the next round of design (defining the problems, generating and testing solutions). As the design progresses, there is less and less flexibility for the team to make changes to the design as multiple prior decisions constrain the next set of solutions. Just as early design decisions shape a project, Merschbrock and Wahid (2013) found that documentation tools constrained the downstream players' work flow. They referred to this as "backward interdependence", where downstream players in a construction project were reliant upon the form of the drawings, data and models generated in earlier project phases. Where there were misalignments between the types of inputs needed and the documents received, these downstream players, e.g., fabricators, had to rework the data into a useable form.

In the 2D documentation process, the design and construction team had a clear understanding of their role in generating documents. The level of detail was closely managed with architects and engineers leaving drawings schematic when they knew the construction detailers would complete the higher level of detail in the shop drawings. With imprecise documents, these designers relied on their own communication strategies as well as the expertise of downstream players to interpret the design intent contained in the project documents (Whyte et al. 2008).

With modeling tools, design and construction teams can build highly detailed models early in the design process, thereby supporting more detailed analysis of alternatives in early design phases (Eastman et al. 2008). This is the classic BIM argument that is portrayed and discussed with the MacLeamy Curve – BIM allows for more detailed information earlier in the design phase (Smith & Tardif 2009). What we find in this study is that while BIM affordances support improved clarity in the communication of design intent and an ability for higher detailed testing and analysis in design, this very detail conflicts with a need for higher levels of interpretive flexibility for generating novel solutions and choices.

METHODS: STUDYING TEAM ROUTINES AND PRACTICES

Over the past five years, we have studied three different building projects that use BIM, which is capable of integrating design and construction databases to foster collaborative work among teams. 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 & Strauss 1967; Strauss & Corbin 1990) using Altas.ti qualitative coding software. 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 matrices while continuing to collect data (Miles & Huberman 1994). We verified the conceptual categories through comparison with the general themes articulated in interview data from over 70 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. In this paper, we focus on one of the teams in one of the three cases and explore this team's adaptation of and to a new technology.

MODEL: INTERPRETIVE FLEXIBILITY AND THE PRICE OF DOCUMENTATION

To understand the conflicts we observed between design practices based on 2D documentation and the introduction of Building Information Modeling where teams worked with 3D models, we first develop a conceptual framework were we see an inverse relationship between the level of development in the documentation and interpretive flexibility. Interpretive flexibility does two things for the team. When a shared object is open to interpretation, the experts mentally fill in the details or have the space to generate new ideas around the schematic shape or read into the object conditions and concerns of their own (Star & Griesemer 1989). Consequently, we argue that higher interpretive flexibility allows for the generation of new ideas and solutions. This connotes then that there is a price of documentation to committing objects to a model. When objects are placed in the model, they obtain a fixity that then must be overcome to make further design changes. The price of documentation include an opportunity cost of unimagined solutions as well as the real cost of labor to modify models once developed. First is the opportunity cost of options that were not discovered because of the model's level of detail limits creativity. The more that is contained in the document, the harder it is to imagine something different. The second cost associated with the price of documentation is that once a model is made, the modeler is reluctant to make changes because it costs them time to modify the model. In this paper, we will focus on the opportunity cost of unimagined solutions.

As Figure 1a illustrates, Project knowledge, both explicit, (documented through drawings, models and specifications) as well as tacit knowledge, (in the minds of the project team experts), increases as the level of development increases. As design decisions are made and recorded, the volume of documents (Figure 1c) increases. The level of detail typically increases, moving from more abstract representation (such as illustrated by the BIM Level of Development (LOD) 100) to more specific representation (LOD 350 and 400).

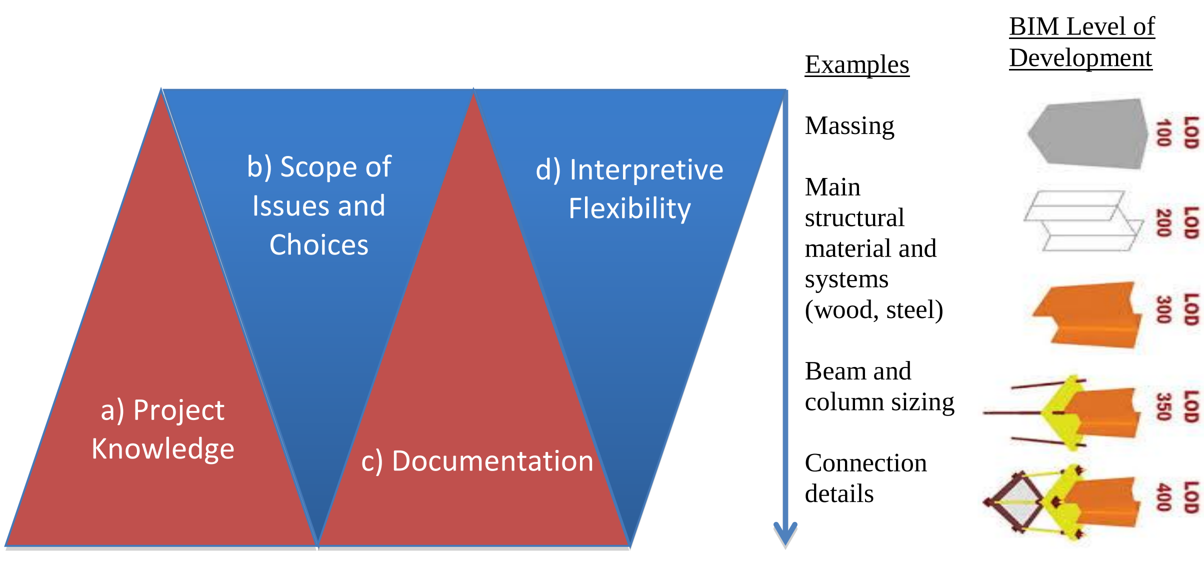

Figure 1: Interpretive Flexibility and the Level of Development

As the design develops from abstractions to concrete visual descriptions, the design process typically moves from broad sweeping issues, such as the overall shape of the building to more narrowly defined issues, such as the connection details (Figure 1b). Consequently, as designers make and document decisions, the breadth and scope of the issues and choices narrows, while the documentation increases with the increase in level of development (LOD) in a BIM. Likewise, as project knowledge increases, as more decisions have been made and documented, the interpretive flexibility of those documents decreases (Figure 1d). It is clear in the example shown in Figure 1 that at the level 400, the column rests on a footing with four bolts in the corners, while this is not made explicit in LOD 300. Based on the LOD 300, the architect might assume that the column would have a bolted connection, but the structural engineer may think that the connection requires other details. Before the connection detail decision is documented and made explicit in the model, this system is open to interpretation by project stakeholders.

At higher levels of development, the scope of the issue and subsequent choice is more bounded and contained by previous decisions in the design process. The project documents provide the context for the problem definition, and thereby frame the problem. Project experts review these documents to discover yet to be resolved issues and then make choices about solving these issues. At each level of the process, the scope of the issues is defined by the prior solution set and the documents used to document those decisions. Particularly in multi-disciplinary teams, documents are enlisted to capture and communicate the decisions in place. The team member then interprets the drawing through their own disciplinary lens and defines the disciplinary specific issues, constraints and choices. In this way, the affordances of the documents (degree of interpretive flexibility) shape the communication in multidisciplinary teams.

BIM for Discovery and Testing

From interviews and observations, we find that the affordances of BIM change the landscape of design and construction team interactions. While on the one hand, clarity of the 3D representation of BIM produces communication of issues and defines problems, on the other hand design and construction teams need interpretive flexibility and malleability produced novel and creative results/solution (Dossick and Neff 2011). We found that the lower interpretive flexibility benefits the process of developing and coordinating detailed shop drawings. In this setting, the project experts need lower levels of interpretive flexibility. At this point in the design development, interpretive flexibility is a liability, because misinterpretation leads to costly conflicts in the field. As one MEP coordinator explained:

> Well, but we're really building digitally first - we are building it both ways. And when you think back to - take BIM off the table - and engineers, people who are good at construction are doing it mentally, they are building it in their minds first. And what you're doing - here's what I see, here's how I see that interacting. Now it's in 3D and it's so much easier for everybody else to communicate and understand: oh, that's what you mean. There's so many - especially when you're talking elevations of things and cuts through things, people visualize it differently and if you can bring that down to - it's more of a fact, this is where it is. And, I guess, in that instance I'd use the communication of the coordinations, MEP systems. When you look at it - I don't know if you've had a chance to go into a light table coordination anywhere?... The old ones I remember, they were always in the room you didn't want to be in because it's full of smoke. Everybody is in a bad attitude and they're - you know, what elevation are you at? I see that your line is hitting mine, what elevation are you at? So lots of calculations, OK, well my

> top of height is at this elevation and I transition - so they're describing from this line to this line I'm at this elevation, and then I transition. And the other person is saying - well, I'm at this - so they're both mentally putting together exactly where did that occur and how many inches does one of them need to move in order to solve that. Well, in 3D, it's plain as day. You can see it and it's very easy for people to approximate - oh, you mean if I moved, it looks like I've got 10 or 12 inches, but if I just moved 4, do you think that would do it? So it's a completely different conversation, no more is it an adversarial - what elevation are you at, it's more a matter of oh, well, we're just barely hitting there, I could just move it a ways. Or no, that's a real issue, now you pull somebody else into a discussion, it is an issue of - there just isn't enough ceiling space. But even that kind of thing, you know, it's not an adversarial conversation between those two people, they're not fighting for that space, they are now saying - hey, Mr. Architect or Mr. Designer, you didn't give us enough room for both of these systems. So it's just different, it changes the landscape.

What this builder describes is the clarity that 3D brings to the problem definition and the communication of that problem to people outside of the immediate team who understand it. We heard this repeatedly in the interviews from builders. BIM helped in conversations with designers and owners because it made the issue clear, and the team could spend the meeting discussing options and choices. The level of detail matched the issue at hand.

BIM for Solution Generation

In architectural interviews, designers echoed the downstream communication benefits that the builders voiced, new 3D and BIM models were powerful for communicating design decisions (having reduced interpretive flexibility) to other project participants, but architects found these tools to be overly constraining in terms of both problem definition and solution generation. It is our analysis that what BIM technology speeds up the design process. With this technology, designers can draw higher levels of detail early in the project. This is the vision and hype around BIM. BIM allows designers to develop and test in 3D models and associated databases at higher levels of detail. However, these higher level of detail come with the cost of lower levels of interpretive flexibility and a reluctance to change models and documents once they are created.

While in the traditional 2D project documentation process, the development of the documents matched the pace of the design needs (Figure 2). In early phases, they represented higher levels of abstraction, with corresponding high levels of interpretive flexibility. As the design choices were made and documented, the level of detail in the documents increased and the interpretive flexibility decreased. As we saw articulated above in the builders comments, the 2D documents however retained too much interpretive flexibility at the construction phase which caused problems in coordination and resulted, at times, in costly rework in the field. In traditional design processes with 2D drawings, the time and effort required to create the documents created a linear evolution of the documentation. As the design progressed from schematic to detailed design, so to the documentation become more detailed as decisions were made in terms of finer grained levels of detail. Because of the work required to create the drawings, these drawings were not made until the decision was made. As the design became more detailed, the knowledge grew and became explicitly represented in the drawings, narratives and specifications. Meanwhile the interpretive flexibility decreased as the scope of the issues became smaller (moving from large building wide decisions of structural systems, to smaller scale choices about connections). The documentation in this way, matched the level of development and level of knowledge and scope of choices made in the process.

Bringing 3D models and BIM into earlier design phases however reduces the levels of interpretive flexibility. It was this decrease in interpretive flexibility that we found to be in conflict with many of the architect's design practices. As shown in Figure 2, if we bring more detailed three-dimensional modeling into early design, the level of documentation does not reflect the scope of the design choices that architecture and engineering team members need to make. As one architect explained:

> There's almost too much information in them… you can drop in all kinds of things now, beautiful plant materials … what I'm talking about is that there's a kind of abstract nature to a physical model and it's very clear it's an abstract version of the design. Whereas a fully rendered physical model, it comes so close to reality that there's a perception that this is exactly what they're getting. I think certain people when they look at that, they're way beyond that this is actually an abstract idea that has to still be developed quite a bit. There's kind of a gap there, that the architect is really not to where the rendering is showing it to be. . . .

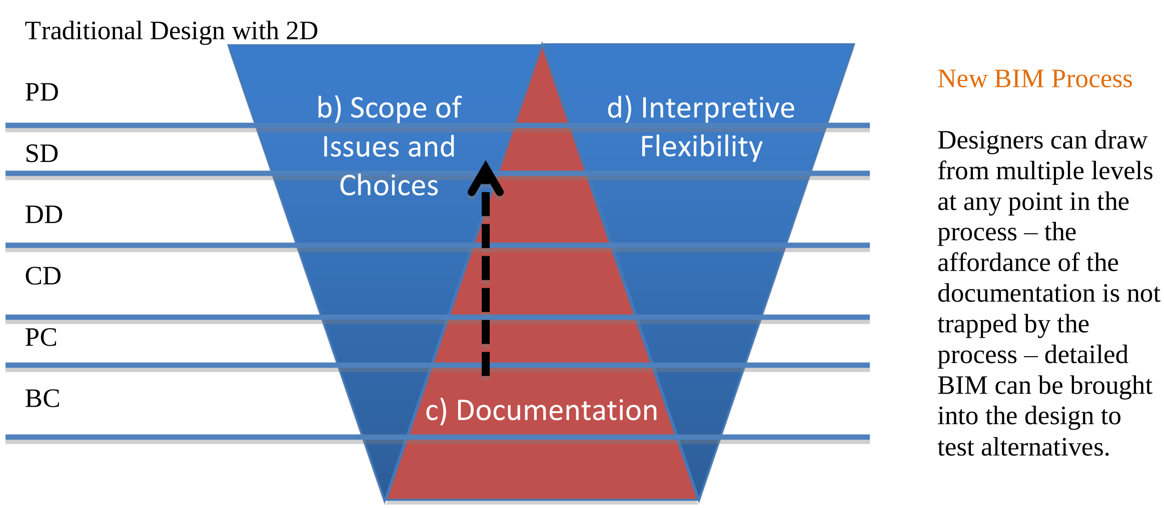

Figure 2. 2D and 3D Design Processes. (PD=Programing, SD = Schematic Design, DD = Detailed Design, CD = Construction Documentation, PC = Procurement, BC = Building Construction)

An engineer described the clarity to be absolute:

> We're no longer drawing, we're no longer representing *a* building, it's no longer representational. . . What we draw is the thing, just scaled down … that's what it is, that's the thing. So any time you have something that's

representational, right off the bat it means that somebody has to interpret it. . . . *You no longer have to interpret what I'm doing.*

For those in the industry who have seen costly mistakes made through misinterpretation, this clarity of BIM is a welcomed documentation tool and reduced interpretive flexibility is a welcomed affordance. However, we propose that the interpretive flexibility needs to match the scope of the issues the team needs to solve. Thus design practices require multiple types of media for exploration and interpretation. There is also an opportunity to develop new practices with 3D models and BIMs that explore abstraction in these tools that retain interpretive flexibility and a sense of exploration that allows for discovery and the imagination of alterative outcomes.

DISCUSSION: BIM OPPORTUNITIES AND CONFLICTS

We have found that the introduction of BIM disrupted the linear documentation process established around the 2D drawing documents by bringing a tool that had higher levels of documentation and lower levels of interpretive flexibility than existing 2D documentation practices. However, it is these higher levels of development that conflicts with the need for interpretive flexibility to match the scope of choices needing to be made in design as it is currently practiced.

The relationship between Malleability and Interpretive Flexibility

We have found in previous work that the interaction around project documents as sites for conversation is richer if the document has the affordance of malleability (Dossick & Neff 2011). We add here the notion of interpretive flexibility as being a critical attribute of documents for shared knowledge creation. While, documents are tacit knowledge placeholders for the creator (Whyte et al. 2008), they provide generative cues to collaborators (Suwa et al. 2000). In Dossick and Neff (2011) we argued that active, informal and flexible tools support messy talk by allowing people to draw, write, sketch, talk, or otherwise modify shared knowledge together. Visual materials, such as Building Information Models, have traditionally been created by participants independently and brought into coordination meetings where they are treated as static entities (Aspin 2007; Whyte et al. 2008). While BIM in this form supports problem definition and explicit knowledge creation, its static (i.e. passive) and "formal" appearance makes it less powerful for joint problem solving. This may foreshorten conversation because, as currently used, these tools limit opportunities for "messier" mutual discovery and unanticipated problem solving at the expense of more efficient or "cleaner" documentation (Dossick and Neff 2011). Whyte et al. (2008) found that when visual materials were owned and negotiated by the team a more effective knowledge development emerged through exploration.

We see two interrelated key affordances for AEC documents: Interpretive Flexibility, which allows experts to see opportunities in the model content, and malleability, which allows them to change the content together in real-time. Both are needed in design and construction teams when we seek the co-creation and synthesis of knowledge across multiple domains. To be generative, shared documents (including models) need to be malleable with interpretive flexibility that matches the scope of the issue so that the team members create a shared mental model of the constraints and have opportunities to envision alternative solutions within these constraints. As one detailer lamented when a colleague suggested an alternative for pipe routing, "I don't know why I didn't think about that option". The representations need to leave room for imagination and create space for disciplinary experts explore new ideas.

Experts cannot be fully uncoupled from the documents

Not only is interpretive flexibility generative in choice-making interactions, but the industry relies on downstream expert knowledge. Documentation is costly to create, and the industry relies on downstream experts to be able to adequately interpret design documents to implement construction. Only some of the tacit knowledge of the designers is transferred through the documents they share. What we have found is that data, analysis and information require domain expertise to interpret, contextualize, communicate and synthesize. Although the tools enable detailed information, the experts are needed to understand the ramifications of the analysis. The initial hype of BIM in the 2000s suggested that experts from across the project process can simply submit their disciplinary data into a shared central database model, and this shared database can then inform others in the project process. Our findings suggest that this technological ideal is flawed. The complexity of building design requires experts to converse with documents. We suggest that the information and the expert cannot be uncoupled. It is this requirement that has lead for the call for integrated practices where architects, engineers, and builders work together with models, data and documents to support higher performance building specifically and better project outcomes generally.

CONCLUSIONS

Owners typically think about the cost to produce design documents. However, in this work, we have found a different price, one of affordance the documents provide to teams as sites for generative conversations. We have found that higher levels of development lead to reduced interpretive flexibility. Not only do our tools need to be malleable in order for the team to "sketch" together as they co-create knowledge, but the representation of the information and data in the shared document needs to have interpretive flexibility in order to generate ideas and solutions. Additionally, the level of interpretive flexibility needs to match the scope of the issue the team is currently working on. We have found that when 3D BIM tools are used, their fixity and clarity works against the generative processes needed in generating novel solutions in design, while at the same time reducing risk and miscommunication in later phases of construction.

In order to adapt and adopt BIM tools to best effect, we need to evaluate the appropriate levels of interpretive flexibility and malleability that best supports the problem and solution development by a team of disciplinary experts at each phase of the process. At earlier phases of the project, a variety of tools, some more abstract for idea generation might be mixed with others tools used to test proposals at finer levels of detail and then translate these findings to the team in more abstract representations that provide generative sites for conversation.

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