Informing Action in Building Information Modeling (BIM) based Multi-Disciplinary Collaboration

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Abstract. The emergence of Building Information Modeling (BIM) in the Architecture, Engineering, Construction and Operations (AECO) industry marks a significant shift in how temporary project networks collaborate to deliver construction projects. While technological solutions to enable this collaborative approach abound, agency and other social aspects of collaborative BIM remain sparsely researched. This paper explores how actions are informed in the deployment of BIM based multi-disciplinary collaboration. Employing a constructivist grounded theoretical approach and based on findings from two in-depth case studies of BIM implementation and deployment, the paper presents five categories that have emerged as being determinant in informing action in BIM-based multi-disciplinary collaboration. It is suggested that seeking alignment within and between these categories will positively inform action in the BIM-based collaboration process.

1. Introduction

Recent developments in the Architecture, Engineering, Construction and Operations (AECO) industry have identified the co-development of a shared digital model, containing a building’s relevant lifecycle information, by a multi-disciplinary project network as a way to improve how projects are delivered and what is being delivered by the industry. Under the moniker Building Information Modeling (BIM), these
developments mark a significant shift in how temporary project teams collaborate. While past research has focused on technological aspects that enable this cross-disciplinary collaboration, recent work has also inquired into the social aspects of this shift, notably the organizational and procedural facets supporting model-based project delivery. However, while collaboration remains a central tenant to work in this field, there lacks a systematic approach to the study of agency and action in collaborative BIM project delivery.

This paper explores how collaborative actions are informed in the deployment of BIM based multi-disciplinary collaboration. Employing a constructivist grounded theoretical approach and based on findings from two in depth case studies, the paper presents these emerging categories and discusses their implications on agency in the development and co-creation of a building information model. Initial findings suggest that a misalignment between and within these categories may result in the failure to successfully implement a collaborative, multi-disciplinary BIM environment. Indeed, an agentic approach to collaborative model-based project delivery, as presented in this paper, intimates consensus and alignment within and between these categories as being a key factor in the deployment of collaborative BIM-based project delivery. A simple, high-level, causal loop diagram illustrates the relationships between the categories.

2. Background

BIM has been characterized as both a tool and a process; it enables the digital construction of a building, or prototyping, prior to its physical construction, capturing all relevant information concerning a building’s design, construction and operation [1, 2]. As stated by the National Institute of Building Science (NiBS) in the US “A basic premise of BIM is collaboration by different stakeholders at different phases of the lifecycle of a facility to insert, extract, update, or modify information in the BIM to support and reflect the roles of that stakeholder.” [3] Evidence suggests that better collaboration through BIM will increase project performance [4]. It has been reported that properly implementing BIM on a project basis leads to significant benefits, such as better cost and schedule performance [5], better communication and information flow [6, 7], improved quality [5, 8] and increased productivity [7, 9]. These benefits point towards a better, more efficient, project delivery process where
project performance is improved over traditional project delivery methods [5].

While the benefits being reported make a compelling case for BIM, the transition to collaborative BIM is proving to be a considerable challenge. Many studies have been carried out attempting to identify and define specific barriers to BIM adoption [10, 11] as well as determinant factors in the successful implementation of BIM [12-14]. Technological barriers are often seen as the major culprit in the challenges facing multi-disciplinary project teams [15]. The social aspects of collaborative project delivery, however, are increasingly seen as playing a determinant role in the implementation process. In fact, when looking at the most significant barriers to collaborative BIM, issues pertaining to interactions between project team members, for instance willingness to share information, consistently rank amongst the most important issues hindering full collaboration [14]. These issues lie in the development of an adequate collaborative environment in which BIM is deployed: issues such as procurement, delivery mode and contractual requirements [16], individual scope, roles and responsibilities [17, 18] as well as varying levels of competence and maturity within the project team [19] will influence the extent and effectiveness of collaborative BIM. These barriers lead to collaborative BIM failing to deliver on the promise of eliminating what has been coined as information chaos [20], amongst other shortcomings.

Different strategies have addressed these challenges by attempting to formalize BIM-based collaboration, most notable being BIM Project Execution Planning (PxP) [21, 22]. While the guides resulting from the BIM planning exercise lay a foundation for the collaborative BIM effort, by setting goals and objectives and offering technological and procedural guidelines, they don’t address the inherent shift in behavior and agency that is required for BIM to be fully effective. Behavior, motivation, as well as other individual-level constructs (such as trust, culture, identity, etc.) have been tied to project performance and project outcome in the past [23-25]. BIM, being a disruptive technology, exacerbates socio-cognitive barriers within multi-disciplinary project teams and requires a reconfiguration of practice [26]. This will impact behavior, motivation and other individual-level constructs. While setting goals and objectives is seen as a way to mediate this behavior, there is a need to go beyond this approach and understand how to foster conducive behavior as well as reach consensus and alignment between individuals in a project team, in order to appropriately and adequately inform action in multi-disciplinary BIM-based collaboration.
3. Research Methodology

The objective of this study is to investigate agency in multi-disciplinary BIM-based collaboration. As this study iterated between exploratory and explanatory, we employed a constructivist grounded theoretical approach (Fig. 1) [27, 28]. Rooted in the interpretivist paradigm, constructive grounded theory “serves as a way to learn about the worlds we study and a method for developing theories to understand them.” [24, p.10] Through this process we identified categories informing individual action in the BIM-based collaborative project delivery process.

Data was collected through two case studies (Table 1). The cases were chosen due to their complementarity; they allowed the research team to cover a large spectrum of the construction supply chain as well as the project lifecycle.

Table 1 Description of Case Studies

<table>
<thead>
<tr>
<th>Case Study 1</th>
<th>Case Study 2</th>
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<tbody>
<tr>
<td>Case</td>
<td>Specialty mechanical contracting firm adopting and implementing BIM since 2010</td>
</tr>
<tr>
<td>Location</td>
<td>Vancouver (BC), Canada</td>
</tr>
<tr>
<td>Duration</td>
<td>25 months (on-going)</td>
</tr>
<tr>
<td>Perspective</td>
<td>Organization</td>
</tr>
<tr>
<td>Unit of analysis</td>
<td>Individual</td>
</tr>
<tr>
<td>Description</td>
<td>Studied the changes brought on by the adoption of BIM within the organization throughout 6 different projects where BIM was implemented</td>
</tr>
<tr>
<td>Data source</td>
<td>Interviews, meeting observation, field reviews, models and project documents.</td>
</tr>
<tr>
<td>Characteristic</td>
<td>Depth of data collection</td>
</tr>
</tbody>
</table>
We performed a total of 83 interviews over the course of both case studies with a total of 43 interviewees. We also performed surveys (2), observed over 25 project meetings and analyzed meeting minutes. We collected project data such as RFIs, schedules, timesheets, etc. Lastly, we analyzed the various models and studied their development in their respective project settings. All interviews were transcribed and coded in Nvivo [29]. During the coding process, we were looking for keywords, linguistic cues and specific conversation turns, which would inform the higher-level categories. We then developed the categories affecting action through collaborative BIM [30]. Fig. 2 illustrates the coding schema developed, which allowed the elaboration of the various categories informing action in the collaborative BIM environment.

4. Category Development

The analysis of the data collected from the two cases allowed us to identify categories, which emerged as being determinant in informing actions guiding the multi-disciplinary collaborative modeling process. These categories are: expectations, requirements, capabilities, incentives, and intentions. The depth of collaboration within the multi-disciplinary team is greatly influenced by how these categories are addressed and managed within the project team. The categories also interact at varying levels of granularity, namely the individual level, the project level and the organizational level, as discussed by Dossick and Neff [17] and further developed in Table 1. The following develops the five categories:

*Expectations* - The articulation and fulfillment of expectations emerged as one of the foremost categories informing how collaborative actions are
carried out. An expectation is “the strong belief that something will happen or be the case in the future” [31] Each individual project team member has their expectations entrenched in their discipline, in their organization and in their project respectively. In this case, expectations represent what project team member hope to gain from the use of BIM, how they expect to develop and use the model and what they expect to receive from other project team members. For example, the expectation on the mechanical contractors part in case study 01 was that he would receive mechanical models completed to a certain level of development, upon which he could build his pre-fabrication models (spool drawings).

Requirements - A requirement is “a thing that is needed or wanted”[31]. The formalization of expectations leads to requirements. The lack of clear requirements is often cited as one of the top barriers to BIM. Requirements are hierarchical, i.e. different requirements will not carry the same weight. Various project team members formulate them in response to their own needs and wants. For example, contractual requirements set out by the owner will dictate how the model is to be developed and handed-off at the end of the project for his future use. Beyond modeling requirements, stakeholders will have to deal with internal and external project requirements such as building codes and program.

Capabilities - A capability is an individual’s, organization’s or team’s “power or ability to do something”[31]. The notion of capability, otherwise known as competency or maturity, has been explored in past research on information technologies, information systems and BIM [32]. Capabilities act as a moderating factor in the collaborative BIM effort by limiting the extent to which the model can be developed and used within the project team or within a specific organization. For example, in case study 02, a large “capability gap” was observed between the mechanical consultant and the mechanical contractor. This lead to the mechanical model not being fully developed for construction purposes and thus capped the total intrinsic value of the mechanical model.

Incentives - Incentives “motivate or encourage someone to do something”[31]. Incentives come under various forms, namely financial compensation, direct benefits related to the use of a tool or process and other types of gains. They can also have a negative impact, acting as barriers to the full deployment of BIM. For example, the measured reduction in change orders on a project or the measured increase in productivity in the field.

Intentions - An intention is an individual’s “determination to act in a certain way” [33]. Intentions emerge at the individual level and are heavily influenced by the other aforementioned categories. Intentions directly involve agency: behind intention lies motivation. For example, the
architect’s intention towards the modeling process in case study 02 were to simply produce 2D contractual drawings from the model, thus limiting the full development of the model for life cycle use.

Action – Action is seen as the execution of continuous thought, the implementation of practice. In Giddens’s *Structuration theory* [34, p.3] “human action occurs as a durée, a continuous flow of conduct, as does cognition.” For Gidden, individual action occurs within three embedded sets of processes, his stratification model: reflexive monitoring, rationalization and motivation. The five aforementioned categories resonate within this model as they operate within one or a multitude of these processes. Action is the fulfillment of these categories and will be informed through their development and aggregation.

5. Relationships Between Categories

The five categories act and interact to inform individual action in the deployment of BIM-based collaboration; they were found to influence the creation, analysis, exchange and overall use of the model by individuals. The categories are articulated in different ways to inform action: the degree, scale, scope and duration of articulation will vary (Table 2). Furthermore, high-level causal relationships emerge when studying how these categories interact. **Fig. 3** illustrates this high-level causal loop diagram. In this case it represents an ideal situation where the categories inform constructive action in the collaborative deployment of BIM. For example, the causal link between expectations and requirements positively influence each other thus creating a reinforcing loop: as requirements structure the collaborative BIM effort, expectations towards the collaborative BIM process and the outputs from the model are mediated to suit these requirements, which intimates a process of learning. Similarly, capabilities are developed as actions unfold: a reinforcing loop occurs. On the other hand, when actions fulfill requirement or expectations, a balancing loop occurs. Causal links also follow a single direction. For instance, as capabilities are developed through experience and

![Fig. 3 High Level Causal Loop Diagram Representing an Ideal Deployment of Collaborative BIM](image-url)
knowledge capture, understanding of the BIM, the tool and the process, will also be developed which will lead to an evolution of expectations. When requirements are put forth, intentions will be set to meet these requirements. The various articulations of the categories will also play a role in the causal relationship. For example, expectations on the owner’s part will dictate project requirements. On the other hand, an owner’s project requirements will serve to temper project team expectations. Incentives will influence intentions, both individual and at the organizational level. Lastly, the system is neither perfectly isolated (it cannot reach maximum entropy) nor is it balanced. The dynamic nature of collaborative action will result in a transfer of impetus into one or more of the categories, namely the capabilities or incentives categories.

<table>
<thead>
<tr>
<th>Degree</th>
<th>Scale</th>
<th>Scope</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within Category</td>
<td>Individual</td>
<td>Intra-Disciplinary</td>
<td>Temporary</td>
</tr>
<tr>
<td>Between Category</td>
<td>Project Team</td>
<td>Inter-Disciplinary</td>
<td>Project Phase</td>
</tr>
<tr>
<td></td>
<td>Organization</td>
<td>Single-System</td>
<td>Project Lifecycle</td>
</tr>
<tr>
<td></td>
<td>Industry</td>
<td>Multi-System</td>
<td>Permanent</td>
</tr>
</tbody>
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6. Conclusion

This paper set out to investigate agency in multi-disciplinary BIM-based collaborative project delivery in the AECO industry. Through a constructivist grounded theoretical approach, five distinct categories emerged as being core to informing project team members’ action in the collaborative BIM process. Preliminary findings suggest that alignment within these categories, for instance between different project team members expectations towards BIM, will greatly impact the collaborative BIM process. In addition, alignment between categories, for instance between requirements and incentives, will also greatly impact individual action in the collaborative BIM process. This suggests that temporary project networks should seek to reach consensus and align themselves across these categories. A simple, high-level, causal loop diagram further illustrated the relationships between the various categories. Limitations of this study lie in the preliminary nature of the findings and the use of two case studies. Further research is required to further refine the various levels of granularity affecting each category and refine the causal loop diagram. Lastly, further work is needed to validate the impact of each category and further define strategies to encourage alignment.
References

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