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TECHNICAL BOUNDARY SPANNERS AND TRANSLATION: A STUDY OF ENERGY MODELING FOR HIGH PERFORMANCE HOSPITALS

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ABSTRACT

High performance buildings—buildings with the aim of reduced energy and resource use—require that engineering analysis be at the center of an iterative and complex design process that assesses trade-offs, goals, and priorities across engineering and other fields of expertise. It has been observed that teams rarely get this right. Historical, cultural, and technical issues all get in the way of open communication and the integration of technical analysis. In this research, we ask what organizational and communication practices are needed for engineering to translate and design teams to synthesize complex energy modeling into the design of hospital buildings? In this paper we introduce a detailed ethnography of energy modeling during the conceptual phase of a new hospital design where energy modeling falls short of its potential. With cross case comparison, we found that a technically-knowledgeable boundary spanner in the owner organization enriches collaboration between the design team and the owner organization for more accurate and impactful energy modeling and improved translation of the model between team and owner. The energy modeling process became almost more important than the results of the energy model wherein the owner and design team had design-critical conversations about the model inputs and clear knowledge about the owner's goals for the data. We propose that it is in this socially constructed knowledge where real high performance design can occur.

KEYWORDS: Integrated Design, Energy Modeling, Communication, Collaboration, High Performance Buildings

THE GAP: DESIGN PRACTICES, MODELING TOOLS AND TEAMS

One of the most difficult challenges in high performance building is the integration and management of engineering knowledge across the various disciplines (Carrillo and Chinowsky 2006; Levitt 2007; Shelbourn, et al. 2006). However, when teams successfully integrate energy modeling—building system analytics of complex interactions of architecture, engineering, and climate—with architectural and engineering design, their work results in higher performing buildings (AIA-IPD 2007, Reed 2009). For that to happen, energy engineers need to "continually advocate for better energy performance throughout the design, construction, and building start-up process" (Cole and Hatten 2011). The problem is that most common engineering design

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practices favor siloed analyses with little communication of complex computational modeling outside of engineering, and without the interdisciplinary linkages that increase the likelihood of successful high performance design (AEDG 2011, Reed 2009).

Healthcare infrastructure represents a monumental opportunity for energy reduction nationwide, and the complexity of hospital design makes interdisciplinary problem-solving even more important. The building sector consumes approximately 50% of the total energy used in the United States, and healthcare buildings are among the most energy intensive types, accounting for 4% of all energy consumed in the United States (Architecture 2030 n.d.; CBECS 2003). Hospitals are well poised to push for energy efficiency. However, achieving the ambitious energy goals set in the 2030 Challenge will require new thinking and better integration of engineering analysis into the process of design (Loveland et al. 2010; Architecture 2030 n.d.).

While current engineering analysis software is good at modeling solutions, often the challenge is in providing presentations of those solutions most useful for interdisciplinary teams (Flager and Haymaker 2009; Gallaher et. al. 2004). Our previous research found that there is a gap between tools such as Building Information Modeling (BIM) and the teamwork of experts who must jointly interpret and then decide how to implement the analytical results (Dossick and Neff 2011). Interpretation is needed, because engineers, architects, builders, and owners have drastically different mental models and different ways of talking and thinking about their work. These differences, in turn, make the translation of engineering ideas across these professional boundaries difficult (Neff et. al. 2010, Dossick and Neff 2010). Contract structures are only part of the answer. Although there is a push toward Integrated Project Delivery (IPD) or, integrated design, when architectural and engineering design teams work closely with construction planners, delivery methods alone do not insure that energy-engineering analytics are included into design (Cheng, 2016). Successful integration requires collaboration, communication and new engineering integrated design theory and practices.

We argue that engineering design theory needs to expand to include communication among these groups that is a synthesis across the often-conflicting design constraints presented by owners, architects and builders. In this research, we found a particularly important connection between owners and energy modelers because assumptions about the ways people will use the building and their goals for the building are an integral part of energy models. This connection bolsters the argument for the importance of integration across the larger team. In the case studies presented here, siloed practices created confusion across the team, which left energy engineers at a loss as to what types of systems to include in their analysis as well as how to translate their analysis in the larger conversation of the design process. In a set of successful high performing case studies, we found that the broader team of owner's representatives, architects and mechanical engineers coproduced energy models and refined the values of specific inputs, leading to a better translation of the data to the larger owner community for analytics-based decision-making. In this paper, we argue that data requirements of energy models are a vehicle for collaboration and the coproduction of knowledge for high performance building design.

LITERATURE REVIEW

Data creation and joint translation

Computational analysis is at the heart of engineering disciplines (e.g., Martinez, 2010; Kandil et. al., 2010). Energy modelers compile input variables that define the building mass and envelope (architecture), define occupancy and usage (owner), and HVAC systems (mechanical engineering). The energy modeler then interprets the resulting simulation output and reports the results back to the design team. As energy modeling software are very sophisticated, the process of setting up the model and interpreting their results are not straightforward (e.g., Hirsch et al., 2011). Although there is a movement to develop more straightforward energy modeling software for early design investigation (Obanye 2006, Stumpf and Jenicek 2009), energy modelers use their expertise to define the input variables as well as interpret the energy modeling results. In this paper we refer to the input variables and output variables as "data". As the data requirements for energy modeling span multiple disciplines and the results impact several building systems (e.g. envelop), we also observe that these models are co-produced, developed through negotiations between the modeler, design team members, and owner representatives.

Much of simulation tool development in engineering has focused on the translation of team design processes into technology—that is, codifying, formalizing, digitizing, and "informationalizing" conversations and collaborative work (e.g., Kivrak et. al., 2008; Tan et. al., 2007). In other words, engineering tools need to be able to be used for explaining the results to others on the design team and within the decision-making structures of a project (e.g. owners). Consequently, translating energy data requires a coordinated effort to make sense of different team member needs for data, owner energy goals, and the alignment of goals between team members and owners. This sensemaking process (Weick, 1995) between team members and owners around needs, goals, and goal alignment shapes the coordinated effort between multiple design team members to create, analyze, translate and synthesize energy modeling. In other words, for team members to effectively create and translate data, they need to first make sense of the conflicting and sometimes ambiguous needs for data across the team. Having greater interactions with owners about their building's operations and energy design interests can help to quickly *make sense* of owner needs and goals, interpret these goals into energy design ideas, and translate data back to the owner in a meaningful way.

Another key challenge in translation is that engineers and architects have differing opinions as to how to best portray and communicate design concepts (simulations, single drawings, past experience) although there was common agreement that concepts are useful only when comparable to others. De Paula et al. (2013) suggested that new organizational forms for the design team should be explored in which the energy consultant works directly with the architect in order to provide simultaneous and continuous feedback (instead of separate analysis). They suggested that energy modeling mapping can help designers understand the relationship of design disciplines with energy modeling processes and team members can co-create data for simulation and communication with other team members. Our research suggests that greater integration of owner's with engineering expertise into the architect and energy modeler workflows of data production and exchange will help create more effective translations of modeling data for owner decision-making.

Boundary spanners

As energy modeling spans across disciplinary boundaries, in this analysis we tap into the organizational theories of boundary spanners and boundary spanning. As the name implies, people who play boundary spanning roles are often members of two groups and thereby able to span between these groups. Haas refines the distinctions between boundary spanners, gatekeepers and knowledge brokers in that boundary spanners "have many different functions, including information exchange and access to clients and resources, whereas gatekeepers focus on information gathering and knowledge transfer. Knowledge brokers share similar characteristics as gatekeepers, but span groups to which they do not belong."(2014: 21). Friedman and Podolny suggested that boundary spanning is not necessarily limited to one person. In studying labor negotiations, they found different members of the opposing groups brokering task-orientated ties (e.g. advice), while others brokered socioemotional ties (e.g., trust) (1992). In engineering contexts, there is a distinction between technical boundary spanning and cultural boundary spanning. For example, DiMarco, M., Taylor, J., & Alin, P. (2010) found cultural boundary spanners to be important in culturally diverse teams. Fellows and Liu found that in engineering projects boundary spanning "between different communities of knowledge and of practice involves issues of comprehension and translation between the communities to ensure clarity of meaning (and purpose)" (2012: 658). It was this last observation - boundary spanner as someone to translate between practice communities that we leverage in this paper. We found that as an explicit source of energy modeling input (i.e., anticipated building usage) and energy goals, the owner's representatives played a key boundary spanning role in high performance building design, helping modelers refine their models and effectively translating the validity of the data to hospital boards.

RESEARCH METHODOLOGY

For two years we studied three different energy engineers who have translated energy modeling analysis to building teams and negotiated with fellow design team members the ramifications this analysis has on the resulting design. The goal of our project is interventionist in that we seek to help teams improve their collaboration in order to support environmental sustainability goals. We conducted 20 interviews across the U.S., 32 interviews with participants during case studies of 8 different projects, 313 hours of field observations of energy modelers at work both in their offices and at consultant meetings, and 12 interviews with people who were part of our field sites. We wrote 297,753 words of written field notes over a period of 24 months.

We 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). 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 and Huberman, 1994). We verified the conceptual categories through comparison with the general themes articulated in data gathered from 20 independent interviews of architects, engineers and builders on how the transition to new energy modeling technology influences communication and collaboration. In addition to the independent interviews, we developed eight case studies of high performing hospitals by interviewing owner representatives, architects, engineers and energy modelers for each case. This method allowed us to make cross-case comparisons and confirm that the practices that we observed in our ethnographic cases reflect the concerns and issues of our interview respondents and that our observations resonate with the articulated challenges facing such teams more generally.

FINDINGS: OWNER ORGANIZATION IS A CRITICAL TEAM MEMBER

In this section we present a case study that highlights how integral the owner is in data production and translation for building design and decision-making. Energy modeling creates a more explicit link between the owner and the design. We first present the case context. Then the case analysis is presented in three sections: how the team created energy modeling data; how the team translated the energy modeling data and output, and finally how they made decisions. Our overarching conclusion is that the energy modeling process specifically and high performance design in general wants deeper owner understanding and involvement than industry norms provide. However, this deeper involvement between owner and team also requires a shared understanding of the disciplinary requirements, their relationships and the priories across the project.

Happy Valley Hospital: The Need for Boundary Spanner Revealed

We observed the conceptual design phase of a new hospital project (over 500,000 square feet) at the elbow of the energy modeler. This included the work of an energy sub-team led by Franklin, the architecture firm's sustainable design leader, two mechanical engineers from an ME firm, and two energy consultants, including Tom, the energy modeler. Robert was the primary owner representative interacting with the team; notably he had limited engineering knowledge, and was not able to span the boundaries between engineering and owner knowledge and goals.

Due to the lack of an owner boundary spanner, two communication issues arose for the energy sub-team: 1) the owner expectations were unclear, and 2) the owner's representative was not knowledgeable about energy and owner representatives with this knowledge were not at the meetings. These communication issues led to increased speculation in the design team about whether energy was a priority for the owner, about what types of systems the owner wanted, and about how to best translate energy model results back to the owner for decision-making. These communication and coordination issues conflicted with the energy modeling requirements for rich and iterative data development, leaving the energy modelers feeling frustrated and struggling to reconcile design information as they received it.

Making Data is a Team Process

At the beginning of design, the only information the team had about owner goals were the owner's inclusion of a target Energy Use Intensity (EUI) of 135 in the Request for Proposals (RFP). Inspired by the owner's target EUI, Franklin began setting expectations across the team and to Robert about how modeling data and system design ideas could help the Happy Valley board make decisions about building system options. Franklin, a vocal advocate for higher performing energy design, adopted the concept of integrated system options, or *bundles*, to emphasize the value of selected building systems (the building's facade, mechanical systems, lighting and controls, and power plant) as an integrated whole, represented by different energy modeling results (i.e., EUI numbers) where choices could be made based on estimates of first costs, energy savings, and ROI (return on investment) for different bundles of building systems.

Armed with the concept of bundles, the energy sub-team held a sustainability workshop where they educated the hospital's facilities personal about the bundle approach. During this event, the facilities staff had the opportunity to create their own bundles out of sticky notes that they could attach to a series of posters representing targets of 135 EUI, Arch 2030, and Net-Zero. By the end of the exercise, the Arch 2030 poster had the largest number of sticky note bundles.

After the workshop, the energy team decided to adapt some of the systems that the facilities staff had selected and created a 135 EUI bundle to model. The team also considered testing an Arch 2030 bundle as the team felt, based on the charrette and the RFP that the owner had a potential interest in a more aggressive goal. Through the workshop, the design team and facilities co-produced data in the form of building systems that shaped inputs for the energy model. Tom refined and selected systems based on the sticky note bundles for his model.

Translating Data as a Team without a Boundary Spanner

During the month following the sustainability workshop, the energy sub-team met once a week at the architecture office to prepare for a Best Options meeting that was intended to present to the owner team several bundle options for further study in Schematic Design. During this period, confusion emerged in the energy team about the owner's goals and whether the owner's drivers for decision-making were based on values of sustainability or first costs. For example, after the sustainability workshop, Franklin shared a story with the modelers about how Robert had shown a great interest in the Net Zero (50 EUI) bundle poster and the potential financial savings it represented. When Tom suggested that this story provided insight into the owner's financial drivers, Franklin countered that the owner may have an "aspirational goal." Here, Tom and Franklin engage in sensemaking about the owner's interest in Net Zero. Without further interaction with the owner, ambiguities and inconsistencies about the owner's energy goal versus the financial incentives continued, particularly when the contractors informed the team that they understood that the owner wanting to build the least expensive hospital possible. These conflicting ideas about the owner's goals confused the team as to how they should translate their data (i.e., energy modeling inputs and results) to the owner: whether to prioritize a financial argument based on first cost or one about sustainability and energy leadership.

The resulting document that was used to translate data in the Best Options meeting was a spreadsheet that listed different system categories, such as "comfort delivery" or "utility plant" on separate tabs. Each sheet listed three to four bundles that included a 135 EUI, 80 EUI, or code (estimated to be 225 EUI) bundle. Their selected "best" option was a 135 EUI bundle that included a note that Tom's current energy model output for this bundle was 107 EUI. Each option included the building systems within that bundle, evaluative weighted and rated criteria, and a total score adding up the criteria ratings.

Despite the team's attempts to anticipate the owner's expectations and needs, Robert was confused by the content in the spreadsheet. In particular, Robert couldn't understand the meaning of the 107 EUI model output and its relationship to his hospital's target of 135 EUI. Robert saw the number 107 as having potential financial implications for the hospital in that he conflated the idea that lower energy (107) corresponded to higher first costs in a linear relationship. Robert suggested that the team was trying to achieve more than the target EUI for a baseline. The energy sub-team had to explain to Robert how modeling data fluctuates throughout design and that the systems currently modeling at 107 were typical of hospitals with a similar size and program that were trying to achieve 135.

Without a boundary spanner on the owner team who had expertise in engineering or modeling, Robert was unable to understand the constructed nature of the modeling data as well as unable to help the design team understand the hospital's values and priorities in relation to specific types of systems. Furthermore, Robert, had little knowledge about what types of systems or technologies were acceptable to facilities personnel and operators, who were not present at the Best Options meeting. For example, during the modelers' site visit, the hospital's facilities leaders expressed that they were open to new energy saving systems such as chilled beams. When a bundle option was presented to Robert during the Best Options meeting that included chilled beams, Robert said that he felt that chilled beams might "freak out facilities." Without an owner representative with facilities or engineering knowledge at the table, the team was left with unanswered questions about what systems might be acceptable and what types of higher performing systems the owner decision-makers were willing to invest in.

Final Data Translation

While the Best Options meeting was less successful at translating the modeling data for Robert, the team reached agreement to present a 135 EUI option as well as a "reach" option to the Happy Valley board that included chilled beams. The ME team then met with owner representatives alone to make specific decisions on building systems. Without the modelers present at this meeting, the modelers did not have the opportunity to consult with the owner about how these decisions would affect the building's energy use. Instead, the engineers informed the modelers about energy design decisions that shaped the model's inputs during a later energy sub-team meeting. These energy design decisions were then written in a "narrative" document that would be provided to the owner for decision-making. Franklin chose to not list information about the current modeling output in the "narrative" and instead translated the data and system choices through the use of the owner's targeted 135 EUI. Evidence that the key owner representative lacked engineering knowledge led to a decision to not share modeling data with the owner, further removing the owner from the nuances of the model itself.

CROSS-CASE COMPARISON

Happy Valley showed us that owner direction is integral to design in terms of priorities and feedback to determine energy goals and system selection. When energy modelers understand the owner's decision-making priorities, they translate the energy model analysis to support owner's decision making. To understand the relationship between this translation and boundary spanning, we compared Happy Valley to one of our high performing case studies. What is striking about this case in comparison to Happy Valley is the integral role that the owner representative played in the processes of establishing energy goals, making data as a team, and working with the team to translate data for owner-based decisions. This case also illustrates the importance of integrating energy modelers to create frequent communication between modelers, designers, and building users and operators as access to direct knowledge about a building's user groups and operations supports data integrity. In this case, a boundary spanner (mechanical engineer working for the owner) supported integration of owner and modeler.

The Smithtown Hospital Story: Modeler-Owner Coproduction of Energy Modeling

Unlike Happy Valley, the Smithtown project had the building systems engineer and the director of facilities take on the role of owner representatives for the hospital design. These owner representatives worked closely with the energy modeler, taking an active participatory role in the model's production. Both owner representatives had substantial engineering knowledge, with the building systems engineer having worked previously as an engineering specialist for an HVAC company. The building systems engineer noted that their team wanted the systems design of the new building to be more energy efficient versions of existing technologies used in other hospital facilities. He also noted that they did not want their hospital staff to have to change their behaviors. This provided a clear and fairly sophisticated technical goal for the design and modeling team and limited guesswork for the design and modeling team about owner's energy values and goals: goals were clear and transparent. In addition, the owner representatives were also advocates for setting and achieving these goals within the hospital organization.

In the Smithtown project, the energy modeler played a dual role on the team, also acting as a mechanical design engineer. The modeler's responsibilities were to take part in energy saving conversations in the design team, to provide analysis and feedback, to coordinate with the utility company to determine financial incentives throughout design, and to design the systems while participating in all design team meetings. One of the owner representatives viewed the highly integrated modeler's role on the team as key, stating, "he wasn't just an apprentice to the engineers. He was part of that team, you know, which was really helpful, I think."

The modeler worked directly with the owner representatives and attended user group meetings. Through these interactions, the modeler obtained user behavior and baseline modeling assumptions as input for the energy model. The owner representatives reported that their energy model inputs included "practical real-world data", case studies of already constructed hospitals, and "new data". The director of facilities remembered "numerous" discussions with the modeler and that these discussions occurred "all the time" adding, "he would come up with things, prove them out, and then come to us and say, 'Look at this'." Here, the modeler and owner representatives engaged in the co-production of modeling inputs, ensuring that data inputs are part of a team decision-making process that best represents the operational and user behavioral realities of the hospital as well as the building systems the design team wants to evaluate.

When recalling details of these discussions, the owner representatives described processes of knowledge and data co-production with the modeler. In one example, the owner representative reflected on how his own experience with the building influenced the inputs in the model and helped the modeler understand the input variables. As the building systems engineer described,

> . . . our real-world data really was beneficial … the assumption on discharge air temperature reset off the handlers. So it was a very big component of the energy savings and his assumptions were very conservative and I was the other way and I was trained to convince him that, no, these numbers do make sense. And I would be able to share with him trend data that I had from other systems to validate that.

Here, meeting the goal and building the model became an owner-designer-modeler team effort. This effort allowed for the co-production of knowledge and data inputs that drew from their experiences, expertise, and owner information about user behaviors and the hospital culture. This led to efficient design decision-making based on mutually agreed upon data inputs and outputs that the owner representative understood. The model's output was then shared between the modeler and owners through spreadsheets and graphics for decision-making that the owner representatives could then translate and share with the hospital board.

Avery Place – Boundary Spanner crisis, but effective translation

In this cross case comparison, having an owner-based boundary spanner was not always a positive organizational strategy, but could still provide cues to how to best translate data to the owner. Avery Place was a new psychiatric hospital with a mix of in-patient and out-patient rooms. The RFP had stated that the owner wanted something "very high performing." The ME and architect team negotiated how to interpret a "high performing" goal into three specific EUI goals (60, 80, and 110 EUI). The ME firm developed a set of three system options systems (VAV, chilled beams, and radiant heating) that would achieve the target EUIs. Other members of the ME firm would produce the models in another office location under supervision of one of the lead ME team members.

While the engineering team had their modeler create a VAV baseline model and a higher performing iteration model with chilled beams, the owner team underwent a major transformation in personnel. In this transition, the team learned that a new CEO had taken over and wanted to create the cheapest building possible according to code. This new CEO also hired an engineering consultant as a part of the owner representation team that could translate the value of the designers' engineering ideas to the owner. This new consultant began suggesting cheaper and less efficient gas-powered systems to use in the building, which left the ME team "cringing." Their goals now misaligned with the owner, the ME team needed to find a way to financially advocate for the higher performing designs.

To work through this paradigm shift, the ME team sought to maximize possible utility incentives and to confirm their calculated rate forecasts for electricity. Through conversations with the utility company, they determined that they should create for the utility company a new lower performing baseline model that incorporated the owner's new system suggestions. This would help maximize their utility incentive as comparing a code level inefficient energy model with a VAV model and chilled beams model would provide a larger incentive based on the greater difference between code and the energy use of the higher performing designs. The ME team also agreed to provide the utility company with their rate forecasts to confirm their calculations.

Despite the need to create a lower performing baseline model, the engineering team proceeded to present the VAV design as their baseline to the owner during a phone conference meeting. While they were successful getting the owner team to sign off on pursuing VAV and other high performing options, the new engineering consultant on the owner team would reiterate his interest in lower performing systems and desire for predominantly gas powered systems. The ME team responded that through their discussions with the utility they learned that there would not be major electricity rate fluctuations. At the end of the call that they informed the group that they had already begin working with the utility company about possible incentive rebates.

After the call, the architect expressed to the engineers his concern that the hospital wanted "to drive things to lowest first cost" and questioned whether the owner consultant's suggestions would meet the building code requirements. The ME team confirmed that the suggestions were code compliant, but as one engineer noted, the consultant's suggestions were "a big setback energy-wise."

Here, while the owner team hired an engineering consultant who could act as a boundary spanner between the design team and the owner team, this particular boundary spanner was not aligned with the energy goals of the design team itself: goals that had been initiated by the owner earlier in the design phase. This change in goal shift on the owner side created a disjuncture in the goal alignment between the owner and design team and created data production and data translation work for the design team to build an argument for higher performing systems as a financial investment. Therefore having an owner-side boundary spanner with engineering and/or modeling knowledge does not on its own ensure that a higher performing building design is an outcome: owner-designer-modelers need to have project goal alignment. However, having access to an owner boundary spanner did provide the ME team with cues that they had to translate their data and design ideas in a way that aligned with the financial goals of the owner team: they had to ensure they could generate a utility incentive and validate their rate forecasts so that they could portray the designers' goals of high performing design and the owner's budgetary goals as aligned.

DISCUSSION

Having a technical boundary spanner who was knowledgeable about energy modeling as owner representative and who was integrated in communication practices of interpretation, modeling co-production and data translation provided a greater context about owner goals and needs, about how to respond to the owner goals in energy design ideas, and about how to translate energy data back to the broader owner organization. Fellows and Liu suggested that boundary spanners create clarity (2012). The cases of Happy Valley and Smithtown provide the negative and positive examples of this social phenomenon. In Happy Valley, the lack of an technical boundary spanner as owner representative led to ambiguity and inconsistency about owner goals, leading to team confusion, unsuccessful data translation, and the further removal of the owner from the energy modeling process. Here the owner representative had the role of gatekeeper (Haas 2014) which was not sufficient when deeper integration was needed. In contrast, in Smithtown, having technically fluent owner representatives working closely with the modeler led to greater clarity around owner goals and the co-production of data inputs that drew from owner experiences, expertise, and user behaviors. This led to efficient design decision-making, helped translate modeling data back to the hospital board, and ensured the model's validity as representative of realistic hospital working conditions.

What is important here is that the energy model (inputs) are co-produced. The owner representative(s) and the design team need to translate the energy and economic goals of the organization into numerical inputs to the energy model. These need to be reconciled with the architectural design intent (e.g., façade), building use patterns and building system choices. The design team needs to understand the ramifications of the energy modeling results in terms of design options (De Paula et al 2013) while the owner organization needs to understand the design team's design options and recommendations, (behind which energy modeling is one or many analytical processes). These work of creating energy models go beyond simple translation, but is a complex co-production of knowledge and analysis. Here we go beyond De Paula et al. (2013)'s recommendation of integrating architecture with energy modeling. We suggest that successful high performing building design (and subsequent operations) is greatly supported when the organization of the project team includes technically knowledgeable representatives from the owner's user and operations groups.

In our study, the energy modeler or engineer as modeler interpreted goals in a way that advocated for design decisions to lower energy use. A modeler might "sell" their ideas to the design team and who in turn sell the design to the owner as "utility saving" ideas if high-energy performance was not part of the rhetoric of the owner or design team. In the case of Happy Valley and Avery, this "selling" of ideas consists of translating the data in a way that portrayed higher performing systems as a financial investment. In Smithtown, having an owner-based technical boundary spanner increased interaction and generated mutual understanding between modelers and owners that intensified the possibilities for innovation and learning. These engineering-savvy owner representatives acted as linguistic and cultural translators: they knew what information the design team needed, what the energy modeling data requirements were, how to navigate the owner organization and culture, how to educate decision-makers, when to bring the right people to the conversation around the energy model, and when to champion the energy modeling goals from within the owner organization. Based on this study, we propose that an owner boundary spanner aligns team energy goals and cultural knowledge about the hospital, creates the organizational capacity for more collaboration, more tightly aligns goals among modeler, designer and owner, and increases the chance that the hospital board will chose higher performing design option.

However, these social processes of goal negotiation and interpretation, goal alignment, data creation and translation are fraught with misunderstandings, misaligned goals, irreconcilable conflicting design parameters, and political maneuvers. As seen in Avery Place, owner boundary spanners can work at cross-purposes to the design team. When Avery Place's owner's leadership changed, the goals for the project swung from those that sought energy efficiency to goals that focused on first costs of construction. The owner's representative used his knowledge of mechanical systems and current trends in gas and electric costs to push for higher energy consuming, lower first cost systems against the design team's higher performing proposals. In this case, the owner "knew too much", which led to technical disagreements between this boundary spanner and the design consultants. Despite working at cross-purposes, the ME teams direct access to the owner information about their goals and preferred lower efficient systems allowed the team to work towards building a stronger argument for their initial design options through developing a model to maximize utility incentives and through validating the stability of the utility company's electricity rates.

We can conclude then that a design process results in better energy performance outcomes when a combination of three important sociotechnical structures are in place: 1) the owner's representative is a boundary spanner whose energy goals align with the design team, 2) the energy modeling is more tightly integrated with design decision-making with frequent channels of communication between owner members and energy modelers, and 3) through tighter integration with modeler and owner, the team can negotiate alignment of owner and team member goals and needs. Energy modeling can encourage greater collaboration between owners, modelers and designers as they jointly produce the energy model. The process of creating and using energy models together also helps teams effectively translate data. These "data creation" mechanisms, not simply the technical solutions of energy modeling, can lead to higher performing buildings.

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REFERENCES

AEDG (2011), "Advanced Energy Design Guide for Small to Medium Office Buildings: Achieving 50% Energy Savings Toward a Net Zero Energy Building", Developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, The American

Institute of Architects, Illuminating Engineering Society of North America, U.S. Green Building Council, and the U.S. Department of Energy. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta.

AIA-IPD (2007), "Integrated Project Delivery: A Guide", Version 1, The American Institute of Architects.

Architecture 2030. The 2030 Challenge. http://www.architecture2030.org/2030_challenge/index.html, accessed 9/10/2012.

Carrillo, P. M. and P. Chinowsky (2006). "Exploiting Knowledge Management: The Engineering and Construction Perspective." *Journal of Management in Engineering* 22(1): 2-10.

CBECS: Commercial Buildings Energy Consumption Survey (2003), "U.S. Energy Information Administration, US Department of Energy", http://www.eia.gov/emeu/cbecs/contents.html, accessed 9/16/2011

Cheng, R., (2015) "Integration at Its Finest". Office of Federal High-Performance Green Buildings, General Services Administration, Research Report, April 14.

Cole, J. and M. Hatten (2011) Integrating Energy Engineering & Performance Modeling into the Design Process. BetterBricks, An Initiative of the Northwest Energy Efficiency Alliance.

de Paula, Nathalia, Vanessa G. da Silva, and Silvio B. Melhado. 2013. "Contribution for Integrating Energy Simulation into the Building Design Process." In CIB World Building Congress. Brisbane, Queensland Unviersity of Technology.

Di Marco, M., Taylor, J., and Alin, P. (2010). "Emergence and Role of Cultural Boundary Spanners in Global Engineering Project Networks." J. Manage. Eng., 10.1061/(ASCE)ME.1943-5479.0000019, 123-132.

Dossick, C. S. and G. Neff (2010). "Organizational Divisions in BIM-Enabled Commercial Construction." *Journal of Construction Engineering and Management* 136(4): 459-467

Dossick, C. S. and G. Neff (2011). "Messy talk and clean technology: communication, problem-solving and collaboration using Building Information Modeling." *Engineering Project Organization Journal* 1(2): 83-93.

Fellows, Richard, and Anita M.M. Liu. 2012. "Managing Organizational Interfaces in Engineering Construction Projects: Addressing Fragmentation and Boundary Issues across Multiple Interfaces." Construction Management & Economics 30 (8): 653–71. doi:10.1080/01446193.2012.668199.

Flager, F. and J. Haymaker (2009). "A comparison of Multidisciplinary Design, Analysis and Optimization Processes in the Building Construction and Aerospace." CIFE Technical Report #TR188, Stanford University, December 2009.

Friedman, Raymond A., and Joel Podolny. 1992. "Differentiation of Boundary Spanning Roles: Labor Negotiations and Implications for Role Conflict." Administrative Science Quarterly 37 (1): 28–47. doi:10.2307/2393532.

Gallaher, M. P.; O'Connor, A. C.; Dettbarn, J. L., Jr.; and Gilday, L. T. (2004) "Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry." NIST GCR 04-867; 194 p. August 2004.

Glaser, B.G. and A.L. Strauss (1968), *The Discovery of Grounded Theory*, Chicago: Aldine.

Haas, Aurore. 2014. "Crowding at the Frontier: Knowledge Brokers, Gatekeepers, Boundary Spanners and Marginal-Intersecting Individuals." In XXIIIème conférence annuelle de l'Association Internationale de Management Stratégique - AIMS 2014, Rennes, France. https://basepub.dauphine.fr//handle/123456789/13553.

Hirsch, A.; Pless, S.; Guglielmetti, R.; Tocellini, P.A. (2011). "The Role of Modeling When Designing for Absolute Energy Use Intensity Requirements in a Design-Build Framework". National Renewable Energy Laboratory. *ASHRAE Winter Conference*. Las Vegan, NV.

Kandil, A., K. El-Rayes, and O. El-Anwar (2010) "Optimization Research: Enhancing the Robustness of Large-Scale Multiobjective Optimization in Construction" *Journal Construction Engineering and Management* 136(1):17

Kivrak, S., G. Arslan, I. Dikmen, and M. T. Birgonul. (2008) "Capturing Knowledge in Construction Projects: Knowledge Platform for Contractors", *Journal of Management in Engineering*, 24(2), pg 87

Levitt, R. (2007), "Delivering Global Infrastructure for a Billion New People: Research on Leadership and Management", *ASCE-CIB Construction Research Congress*, Grand Bahamas

Loveland, J., H. Burpee, M. Hatten, and D. Griffin (2010), "Target 100: Re-Envisioning Today's Hospital Prototype for Greatly Improved Energy Efficiency, Human Well-Being and Performance." *ACEEE Summer Study on Energy Efficiency in Buildings*.

Martinez, J. C. (2010), "Methodology for Conducting Discrete-Event Simulation Studies in Construction Engineering and Management", Journal Construction Engineering and Management, 136(1): 3

Miles, M. B., and A.M. Huberman (1994), *Qualitative Data Analysis*, Sage, Thousand Oaks, Calif.

Neff, G., B. Fiore-Silfvast and C. S. Dossick. (2010) "A Case Study of the Failure of Digital Media to Cross Knowledge Boundaries in Virtual Construction", *Information, Communication & Society*. 13(4): 556-573.

Obanye, Ike. 2006. "Integrating Building Energy Simulation into the Architectural Design Process." London. http://cebe.cf.ac.uk/news/events/beecon2006/pdf/P18_Ike_Obanye.pdf, accessed November 15, 2013.

Reed, B. G. and 7 group. (2009), *The Integrative Design Guide to Green Building: Redefining the Practice of Sustainability*. Hoboken, NJ: John Wiley and Sons.

Shelbourn M A, D.M. Bouchlaghem, C. J. Anumba, P. M. Carillo, M. M. K. Khalfan and J. Glass (2006). "Managing Knowledge in the Context of Sustainable Construction." *Journal of Information Technology in Construction* 11: 57-71.

Strauss, A. L., and Corbin, J. M. (1990). *Basics of qualitative research*, Sage, Thousand Oaks, Calif.

Stumpf, A. and Jenicek, E. (2009) "Early Design Energy Analysis Using BIMS (Building Information Models)". *Construction Research Congress*. Seattle, WA. Pp.426-436.

Tan, H. C., P. M. Carrillo, C. J. Anumba, N. (Dino) Bouchlaghem, J. M. Kamara, and C. E. Udeaja (2007) A" Development of a Methodology for Live Capture and Reuse of Project Knowledge in Construction", *Journal of Management in Engineering*, 23(1), pg 18.

Weick, Karl E. 1995. *Sensemaking in Organizations.* Foundations for Organizational Science. Thousand Oaks: Sage Publications.