Implications of New Construction Technology for Western Washington Mechanical Contractors

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Executive Summary

Building Information Models (or "BIM") represent buildings in three-dimensional computer models and associated databases. BIM is at once a visualization tool for depicting the building plans in 3-D, a database of building components that can be queried and filtered, and a collaborative communication tool for linking together various models, datasets and ways of looking at the building. Proponents of BIM technologies promise that the use of the tools will lead to more efficient building, closer collaboration and coordination between subcontractors, and clearer directions for labor resulting in fewer changes and fewer field issues.

The purpose of this report is three-fold. First we describe emerging applications of BIM tools in mechanical design and construction, and establish how these BIM practices support and challenge managers and workers who fabricate and install building systems. Then, we identify the implications of this technology for communication and collaboration among designers, managers and builders, and analyze existing practices in the Architecture, Engineering & Construction (AEC) industries to predict emerging trends in BIM use. Finally, we propose recommendations for mechanical contractors to improve the efficiency and efficacy of their implementations of BIM.

For this study, we analyzed data from our ongoing study of BIM practices at three building construction projects in the Pacific Northwest and from interviews with 125 AEC professionals across the United States. Specifically for this report, with the support of the Mechanical Contractors Association of Western Washington, we interviewed additional mechanical contractors for a total of 21 specialty contractor interviews.

Findings

We find that mechanical contractors are well positioned for the emerging changes in the AEC industry. The ways in which designers and builders manage information and data is challenging existing roles, organizational divisions, and work practices throughout the project process. We have identified four key emerging trends:

- There is an increasingly important role for technologists on project teams
- Mobile computing technologies link the field to the office
- The line is blurring between design and construction
- BIM is enabling and expanding prefabrication.

Recommendations

Based on the analysis outlined in this report, we offer six recommendations:

- Strengthen teams
- Cultivate technology leaders
- Strategize for multiple "BIMs"
- Design environments not programs
- Quantify current practices
- Remember technology is an occasion for change

Communication among architects, engineers, the general contractor, and mechanical and other specialty contractors could be improved through clearer connections among all project participants. For this to occur, strategic change needs to take place in tandem with technological change. Our research shows that although technology alone does not drive change, it can be an opportunity to enable change. Communication among architects, engineers, the general contractor, and mechanical and other specialty contractors could be improved through clearer connections among all project participants.

Contents


Image credit: Student work, ARCH/CM 404

1 Introduction

Currently new tools, such as Building Information Modeling, are used in the design office for analysis, in the construction office for planning and at the field site for layout, coordination and installation. In our research we have documented and analyzed how architects, engineers, and general and specialty contractors use BIM to complete a building project.

1.1 New Construction Technologies in Mechanical Construction

Proponents of BIM technologies promise that the use of BIM tools will lead to more efficient building, closer collaboration and coordination between subcontractors, and clearer directions for labor resulting in fewer changes and fewer field issues. To this end, we sought to gain a better understanding of how 3-D digital models of the buildings support managers and workers who fabricate and install building systems. We also examined the implications of this technology on communication and collaboration between designers, managers and builders. What are the ramifications of BIM for collaboration? Who owns the models and controls them? Who manages the dimension control, layout and field issues? In this report, we introduce the environment and future of BIM for mechanical construction in Western Washington.

1.2 Definition of Terms

We define Building Information Models (BIM) broadly to refer to the hardware and software that allow project participants to model in three-dimensions and to associate data with those components. In this report, we describe many different applications of BIM tools in design and construction.

Virtual Design and Construction (VDC) relates to BIM work practices for design and construction work.

1.3 Methodology

This report draws from an ongoing program of research that began in 2007. Since then, we have interviewed 125 AEC professionals including 21 specialty contractors (17 mechanical contractors, 3 electrical contractors, 1 fire protection contractor), 35 general contractors, 43 architects, 5 owners, and 21 civil, electrical, mechanical and structural engineers across the U.S. In addition, we have observed three MEP detailed-design teams on three different construction projects. One of these projects was part of a longitudinal study of the entire design and construction process, including field coordination activities. For this report, we began by analyzing over 1,000 pages of interview transcripts and 400 pages of field notes to determine how BIM is being used by mechanical contractors for detailing and field installation. We also looked for evidence of how the roles of the subcontractor organizations as well as those of individuals are changing because of the adoption and integration of BIM into the design and construction process. Specifically for this report, we also interviewed key contractors in Western Washington's mechanical contracting community.

The work of mechanical contractors appears to be somewhat of an untold story in the national BIM conversation.

2 Overview of BIM

Building Information Models (or "BIM") represent buildings in three-dimensional computer models and associated databases. BIM is at once a visualization tool for depicting the building plans in 3-D, a database of building components that can be queried and filtered, and a collaborative communication tool for linking together various models, datasets and perspectives of the building.

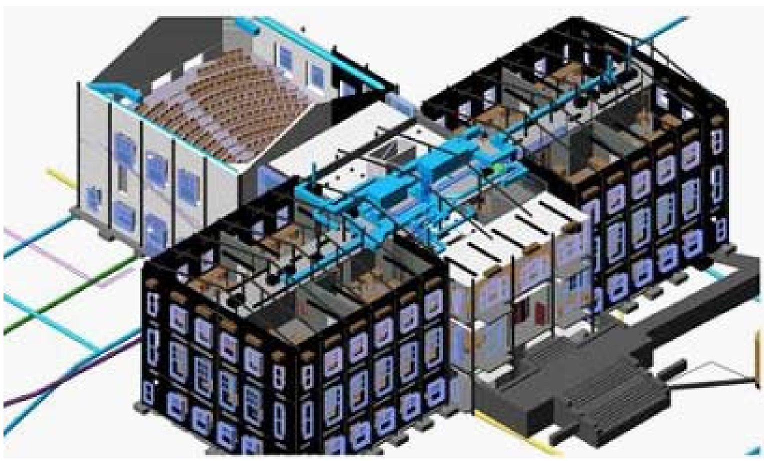


Image credit: Student work

One architect explained BIM as "virtually designing and constructing a project and getting information that can be used or extracted many times in different ways… it means something different to everybody" depending on their professional identities (A071024_NC)[1]. Several other interviewees described the vision of BIM's potential—once the building is represented as data then it can, in theory, be manipulated to complete engineering analyses; architectural and design studies; construction planning, prefabrication and maintenance; and even operations scheduling once the project is complete.

2.1 BIM in Practice

The AEC industry standards have yet to emerge for the data exchange and collaborative work practices necessary to fully leverage the potential of BIM tools. There is currently a tension between the vision that BIM can be a central project database, and the reality of current project delivery practices where project participants share knowledge; exchange dynamic information; coordinate complex systems, requirements and geometries; set schedules and goals; and resolve conflicts in an ever-changing landscape of data, documents and the built reality of site construction. Depending on the goals of the users and the nature of the project, BIM models can be customized to show different levels of detail, exactness of dimensions, and types of data. Thus "not every building has to be modeled exactly the same way" (A071127). Consequently, the kind of BIM model that is generated "depends on what you want the end result to be," such that a model for presenting a building to clients would be different from the model needed for generating construction documents (A071127).

For its proponents, the vision of BIM includes tools and work processes that will enable coordination from design to final construction through seamless collaboration organized by a single virtual model used by all project members. Within this ideal, communication problems are lessened, lengthy formal "Requests for Information" (or RFIs) are avoided, and tighter collaboration is fostered through the use of BIM's technological frameworks. To successfully implement this vision, BIM proponents argue for changes to organizational industry practices to foster closer collaboration. However, this collaborative delivery and central database vision is in direct tension with the current process of distinct models generated in the separate spheres of architecture, engineering, and construction. Some argue that the current organizational separation is inefficient and blocks inter-organizational collaboration at all stages of the building process (CURT 2004). Due to the tensions between the need for central data and model repositories, and the individual models created by separate project participants, what we see emerging is a more complicated, distributed network of scope-specific models that reflect the organizational structures of designers, engineers, consultants, contractors, owners and specialty contractors. Current practices embrace multiple digital models and multiple modes of communication each of which is tailored to the specific needs of the task at hand:

> *"We are seeing contractors building one, two or three models for their own internal use, and not even using the architect's model, even if it's offered to them. And architects are certainly building more than one model…. The model that you want to do energy analysis of is a very different kind of model than you want to do a set of production drawings off. . . . [I]nstead of one set of 2-D drawings, you've got eight, nine, or ten models of the building, all for different purposes, and all being maintained and managed along with a full set of 2-D documentation (A071214)."*

This is the antithesis of how proponents present BIM, as "a single building model where one model would be able to generate everything from structural analysis to energy modeling to visualization to construction simulation" (A071214). Instead we see models which support individual scopes being brought together as distributed networks of models used for specific purposes, where each individually authored model remains under its own organizational jurisdiction.

1 Numbers refer to the researchers' interview labeling system. All respondents are kept confidential in accordance with our research agreements.

More sophisticated BIM users have developed processes and technical capabilities to exchange models with collaborators, or to utilize direct digital exchange to transfer data to different programs, working through the technical hurdles of interoperability. Whether they are consolidated for coordination or digitally exchanged for fabrication, most data and models today are exchanged at specific points in time for specific purposes.

See Figure 1 below.

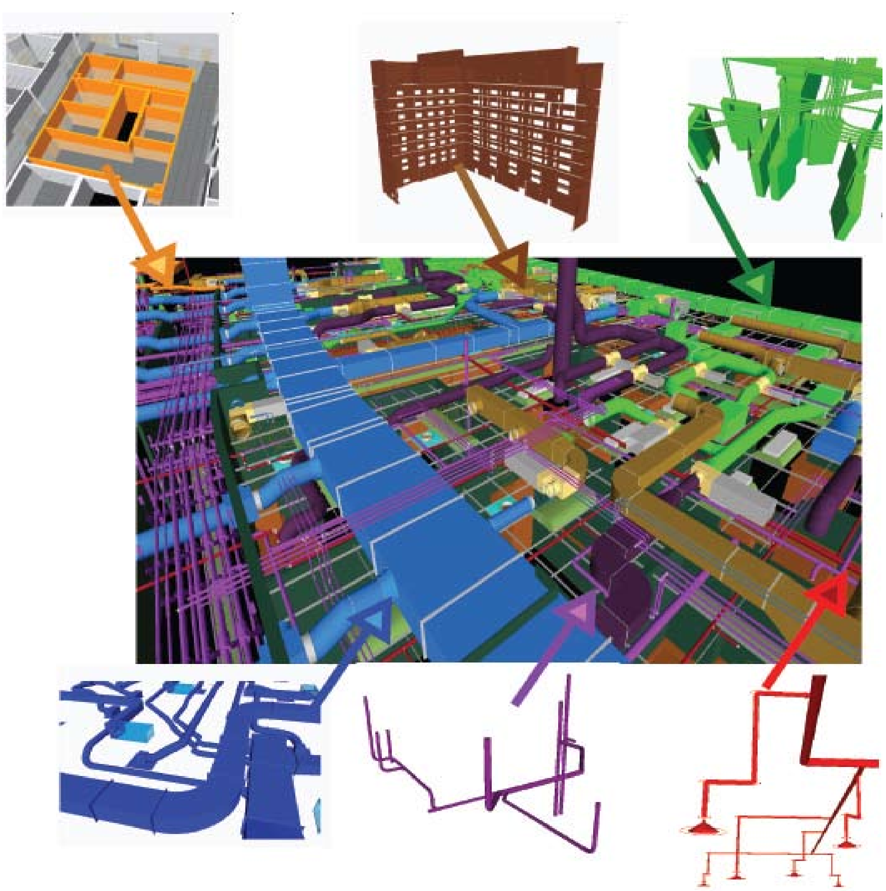
2.2 Trends: How Does Western Washington Measure Up?

This section provides an overview of how BIM is currently being used in Western Washington and how it is impacting the labor practices of the industry. We compare the national trends, as reported in the 2008 and 2009 McGraw-Hill Smart Market reports (Smart Market reports) with those we documented here in Western Washington. We find that in general many of the Western Washington trends are reflected in the Smart Market reports, however the leadership roles that mechanical contractors are playing in BIM adoption in Western Washington is not reflected in the national surveys.

60%

of MEP contractors say they have adopted BIM, which ranks above the average adoption rate of the industry as a whole.

Figure 1: Model of a Distributed BIM Network



2.2.1 BIM Adoption

The adoption of BIM is becoming more pervasive. Today, half of the North American industry is using BIM or BIM-related tools, which is a 75% increase in usage in the last two years. The Smart Market reports found that it is the MEP contractors who are leading the way in BIM adoption. 60% of MEP contractors say they have adopted BIM, which ranks above the average adoption rate of the industry as a whole. To put this number in context, 58% of architects have adopted BIM, and contractors (currently at 49%) are the fastest growing user population, having quadrupled their BIM use in the last two years.

The adoption rates for engineers (42%) and owners (37%) although lower, are nonetheless growing. The Smart Market reports also found that four out of five MEP contractors who use BIM say they are seeing a positive return on investment in the technology, which is more than any of the other user groups.

Given the leadership of mechanical contractors in BIM adoption and use illustrated by these statistics, it was surprising not to find more information about the MEP user group and their relationship to BIM in the Smart Market reports. The 2008 Smart Market report found that the trade contractors are almost never the prime drivers of BIM use on a project (1%). However, based on our observations and interviews, we found

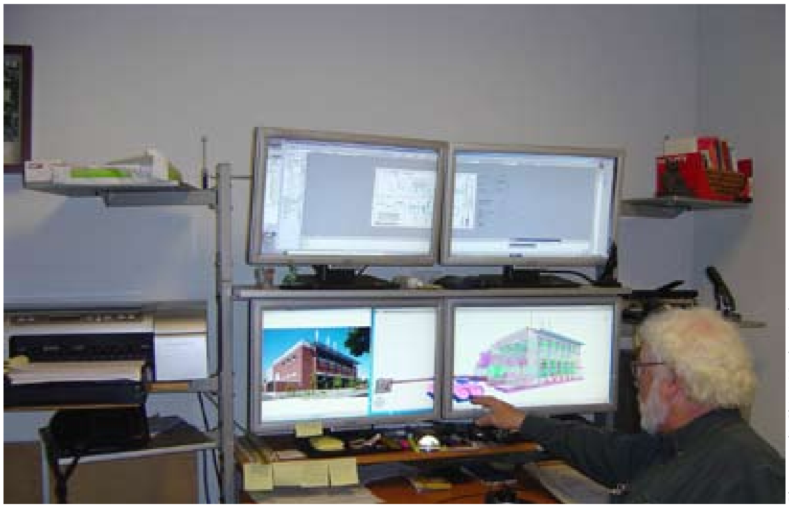


Photo credit: Shinn Mechanical

For MEP contractors, more than other contractors, a high value is placed on using BIM for spatial coordination, the shop drawing process, and driving shop fabrication equipment, as these are the activities most directly relevant to their trades.

that there have been a greater number of times that the mechanical contractors have been the prime driver of the use of BIM.

As the industry has moved to adapting and adopting BIM, mechanical contractors are the "resident experts" who have used BIM-related tools for some time and consequently have the technical expertise to support project-wide BIM efforts. We found that mechanical contractors were often a leader of the MEP coordination because they had the technical expertise necessary for running a BIM-based MEP coordination and/or because they had the largest stake in the project with their systems, and therefore the most risk. In the national reports, there was very little information about mechanical contractors in terms of their contribution and role in the adoption of BIM and even less information about the impact on the work of mechanical contractors and how they coordinate with the other roles on the project. Our findings suggest that mechanical contractors are playing a more important role in BIM adoption and innovation and are more impacted by the use of BIM on construction projects than the Smart Market reports suggest. The work of mechanical contractors appears to be somewhat of an untold story in the national BIM conversation.

2.2.2 BIM Use

Utilizing BIM's 3D modeling and visualization capabilities to communicate is by far the most common use of BIM across the disciplines and trades. For many BIM users this is the primary BIM functionality in their work. Across different industry user groups, 3D modeling and visualization helps design and construction teams see how different systems of the building intersect in space. In a variety of forms, BIM visualizations help to relay the design intent to field coordination team members and then reciprocally to relay field conditions to the design team members. BIM modeling also facilitates interpreting different issues with the building, identifying problems, and testing solutions. Many respondents described how BIM helped during the MEP coordination process by "catch(ing) problems early on" through clash detection and then allowing them to generate a solution in the model before it is a problem out in the field, or before it is a design change that would have cost more time and money.

As reported in the Smart Market reports, the use of BIM analysis tools is also increasingly present on projects. These functions include 4D (scheduling) and 5D (cost estimating), accessibility and construction sequencing, quantity takeoffs, and fabrication. For MEP contractors, more than other contractors, a high value is placed on using BIM for spatial coordination, the shop drawing process, and driving shop fabrication equipment, as these are the activities most directly relevant to their trades. MEP contractors also placed a moderate value on being able to complete quantity takeoffs with BIM. Interestingly, the majority of project participants engaged with BIM are authoring 3D models, with fewer participants actually using the BIM analysis tools. The 2009 Smart Market report found that MEP contractors have the largest percentage of users (44%) that are both authoring and analyzing their models compared to contractors (33%), architects (29%) and engineers (27%).

In general our observations matched the Smart Market report trends that revealed that BIM was emerging on projects to function beyond visualization and clash detection. In fact, users perceive BIM as having high value in the construction and fabrication stages almost as much as it is valued in the design development and construction document phases (Smart Market, 2009). The report suggests that contractors are experiencing the highest value during coordination because that is when the bulk of the costs are generated and the opportunities to save time and money arise. Contractors are using an array of BIM analysis tools to help with scheduling, cost estimating, construction sequencing and accessibility, as well as quantity takeoffs. As BIM reduces conflicts, creates confidence in building plans, and provides detailed information, opportunities for value in fabrication are rapidly expanding. Accurate fabrication of materials reduces waste and preassembly can save time, but of course both of these potential savings depend on the accuracy of the model to predict the final building.

While many different models are being authored for different purposes, these models are not being shared very frequently across organizational boundaries. The 2009 Smart Market report found that a relatively small percentage of users are using BIM analysis tools on existing models created by others (10 % of MEP contactors, 1% of architects, 2% of engineers and 12% of contractors). Our findings also showed BIM users in Washington taking more of a "distributed" approach to modeling, meaning users would author their own model rather than analyze or adapt a pre-existing model created by others. In practice, this means that different design and construction entities author separate models for their own needs. These models include architectural, structural, MEP, site/civil, construction, schedule (4D), cost (5D), fabrication, and operations/facilities models. Interestingly, our research shows that this approach does not necessarily mean that these separately authored models could not be shared, linked, or reliable enough to be used by others. In fact, future trends point to the use of BIM as a more distributed network of models that does link these separately authored models, while each maintains its organizational jurisdiction.

For mechanical contractors there has been a more gradual emergence of BIM related tools in their practice; whereas for other disciplines, including architects and general contractors, there has been a more dramatic shifting of standards and practices around BIM.

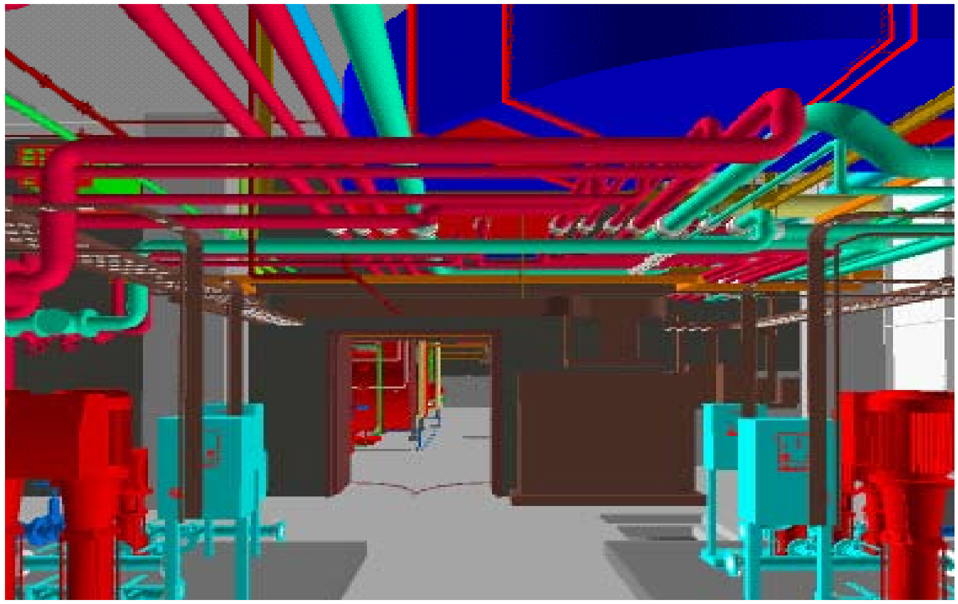
Photo credit: Michael Casey

2.3 BIM is Not New for Mechanical Contractors

One of the main themes we found from our research is that for mechanical contractors there has been a more gradual emergence of BIM related tools in their practice; whereas for other disciplines, including architects and general contractors, there has been a more dramatic shifting of standards and practices around BIM. Since the time 3D modeling tools appeared on the market (some as early as the 1970s), mechanical contractors have been using them to do their work but have not been in the practice of sharing them with other project participants (primarily because others have not been interested in them). Mechanical contractors' 3D modeling practices have been developed in-house and the submittal requirements have, up until recently, been in two-dimensions.

Throughout the years, mechanical contractors have been using 3D modeling primarily for spatial coordination of their own systems and for achieving a level of detail and accuracy in the modeling of their systems to use for fabrication and prefabrication. As a result, mechanical contracting is not facing the intense organizational, technical and cultural shifts that other disciplines in the industry are facing. For those mechanical contractors who have already developed full 3D modeling capabilities in-house, the transition to project-wide BIM adoption has been more gradual. In fact, as was mentioned in section 2.2, these mechanical contractors have found themselves to be leaders and resources for the MEP teams as the other trades try to adopt these technologies. However, mechanical contractors still have work ahead to keep pace with the larger changes in the industry. Specifically, they need to negotiate how to reconcile project-wide BIM adoption with their preferred practices. Not unexpectedly, these already developed, in-house processes will occasionally be at odds with the general contractors', owners' and designers' BIM adoption strategies.

Mechanical contractors are facing new challenges and opportunities as the industry adopts BIM as an inter-



organizational process and other trades begin to utilize BIM tools. While within their organization they have been utilizing the power of 3D modeling for spatial coordination, mechanical contractors are now faced with contributing to and at times coordinating their models with a distributed network of other organization's models that are associated with interdependent dimensions of information Interorganizational BIM presents opportunities for using 3D modeling in new and different ways and it relies more heavily on integrated work practices for effective coordination. Mechanical contractors are often in the position to influence or even direct the project-wide BIM standards, however, more and more general contractors are creating project-wide standards of their own that require mechanical contractors to adapt to these new or different standards on a per-project basis. This can be a source of tension between a well-established work flow that is internal to the mechanical contractor's company and the specific general contractor-directed requirements of the construction project. As the industry emerges from this transitional period, national efforts such as the National BIM Standard-United States, should provide guidelines for project-wide BIM work processes, and mechanical contractors have an important role in shaping these standards.

Prefabrication is also not a new practice for mechanical contractors, but prefabrication is gaining significant attention on the national BIM stage. Enabled by more detailed and accurate BIMs, the amount of prefabrication performed today is on a much larger scale than it has been in the past, which presents new opportunities and challenges for trade practices. As a trade, mechanical contractors within their own organizations have developed a level of technical aptitude that they bring to the emerging inter-organizational prefabrication processes. In many cases, because of their level of technical expertise related to 3D modeling and prefabrication, mechanical contractors are also able to emerge as leaders in the coordination process of multiple trade prefabrication or as managers of other BIM-related practices.

Mechanical contractors are also able to emerge as leaders in the coordination process of multiple trade prefabrication or as managers of other BIM-related practices.

3 Findings

Trends in BIM-enabled Construction

In this section we elaborate on four major trends in BIM-enabled construction and what these trends mean for mechanical contracting. These trends bring to light the emerging roles, technologies, practices, and shifts in mechanical contracting as the trade expands its use of BIM.

3.1 Managing the Distributed Network of BIM Data and Models

As was introduced in section 2.2, often when BIM is discussed in industry publications, standards documents, marketing materials and professional associations, it is referred to as a single project model. Based on observations of designers, contractors, consultants and specialty contractors using BIM tools to date, we find instead that multiple models are generated for different purposes depending on the needs of different users at different times throughout the process. Many of our respondents explained that BIM is not a single "almighty database and everyone can plug into", but rather "it's adapted and readapted and pulled in all these different parallel tracks to serve purposes to the needs of whoever it is at the time." (A071114). In current practices, BIM is a distributed network of models that are connected not only across specialized disciplines but also across time. This is true in the design phases as well as in the construction phases. We find that models are developed in a dispersed and iterative fashion – a process that is more aligned with the organizational structure itself – specialists working on their own models, yet sharing them across distributed networks. The models are then consolidated for collaboration and comparison. However, many models are created, used, and then eclipsed during the course of the design and construction processes. Consequently, a construction project does not have a single BIM, but rather many models that reflect the multiple professional needs and the dynamic and iterative construction process.

Mechanical contractors play a key role in BIM model consumption and creation. In current practice, modelers in mechanical construction translate the design intent into field coordination models. Consequently, there is a need for a close relationship between the MEP engineers and the mechanical contractors who also need to collaborate with other trades throughout the detailing and installation phases. Once created for coordination, the shop drawing BIMs may be used in other ways:

- MEP subcontractors use BIM models to prefabricate their pipe sections or ductwork
- Estimators use the models to calculate accurate accounts of material quantities, design conditions, and equipment to create work plans, make assumptions, and procure materials.
- Field superintendents use BIM to work with field personnel in order to optimize installation sequences
- Schedulers use the BIM to develop and communicate schedule information to the owners and design team, as well as coordinate closely with field supervision
- Surveyors use BIM to shoot coordinates directly from the model to the field – or from the field to the model - to verify the location of the as-built structure for coordination with curtain wall or other finish systems.

As this list illustrates, each role on the construction team has different ways it can use BIM, and each is exploring the potential advancements that such applications offer. Good ideas come from everywhere, and new ways of using BIM are emerging as BIMs become more widely available.

The future of BIM in design and construction is trending towards the distributed network of models for a number of reasons. One is that this approach eliminates the concern of model "ownership" and "authorship" that accompanies a single, consolidated project model, by supporting access for each participant to all of the other project models to pull the information they need. It also empowers users to manage the content of their own model within the specialized software systems designed to support their design, analysis and detailing requirements. If the BIM for a project consists of a distributed set of models, each model can represent the scope of the author, can be solely controlled by the author, and is available and referenced by other project participants. Since each designer and detailer authors their own specific content related to their scope of work, it follows that they should create and maintain their own 3D model for this scope.

There are also technical reasons to support why a distributed network of models is preferable. It is more effective for specialists to use software specifically designed for their work, (such as CADduct, or AutoSPRINK) which may differ significantly in functionality from the software that other project members need to use. There is no single piece of software that is able to fit all the specialists' needs. Subsequently, interoperability becomes paramount. The challenge is to make the different models work with each other so that a network of models may emerge. This requires a central data manager who hosts the models and manages the integration of these models.

3.1.1 Interoperability

The interoperability among models allows for quality control across the disciplines as the various project participants review and engage with each other's models, but it does not threaten the author's control of their own model. BIM as a distributed network of models, individually authored by the different project participants (architects, engineers, specialty contractors, etc.), and linked through interoperable solutions such as Navisworks, needs to allow BIM users to pull information from the network when they need it. A network of models facilitates open and transparent communication across the project team. This may be in the form of the exchange of specific models between project participants at particular hand-off points or it may be in the form of a more central model repository that is available for project participants to query as needed. However, the challenge of interoperability is that the need for different levels of detail or abstraction varies across project activities. For example, a concrete model that was quickly made for an estimate did not articulate all of the slopes in the parking level. This concrete model was not appropriate for MEP coordination because the slopes are very important in that activity. It is difficult to fully anticipate the nature and types of assumptions and understanding others may glean from the shared models. And particularly during this time of transition, when industry norms and standards are nascent, project teams need to communicate the abstractions, assumptions and limitations of the models at each exchange. Such exchanges should detail not only the geometries, materials, and costs of building components, but also the assumptions and abstractions embedded within the current state of design decisions, as well as the assumptions about installation sequences, equipment and access logistics.

While many different models are being authored for different purposes, these models are not being shared very frequently across organizational boundaries.

Photo credit: Assembled Chemical Weapons Alternatives

3.1.2 Emerging Roles

Since the emergence of BIM and networks of models, we have observed new roles and practices within detailing and coordination work. One challenge with the authoring and coordination of multiple BIM models is figuring out how these models will be managed and who will be responsible for making these models technically and organizationally interoperable. Our findings reveal a trend towards an emerging role for BIM managers who are in charge of consolidating different configurations of individually authored models. They oversee the network of models and ensure interoperability.

The traditional role for coordination and management of MEP trades is the MEP coordinator. In some instances, the management of the BIM models has been taken on by the traditional MEP coordinators, and in other projects a new manager has been brought to the team specifically for BIM management. Traditionally, MEP coordination is often filled on the basis of whoever is assuming the greatest risk in the building project in terms of systems. This has historically been the mechanical contractor, who tends to have the largest systems. However, now that MEP coordination involves the use of BIM tools and the consolidation of a distributed network of models, there are new technical and server infrastructure skills that are necessary for this role. Since mechanical contractors come to BIM with a certain technical aptitude in 3D modeling, they have for the most part been well-suited to fill this role. As other professions in the industry improve and expand their use of BIM tools, the management of repositories and integration has been shifting to the general contractors who consider themselves a more neutral party in the MEP coordination activities. However the technological management is assigned, considerable collaboration still occurs across the MEP trades, and detailers report that the models provide a much better platform for scope-model coordination.

The BIM manager - together with the MEP coordinator - needs to both technologically and organizationally coordinate multiple scopes of work. This requires, as one such manager says, "[the] need to make sure all of the trades are represented and all their systems are shown." When the BIM manager is also a detailer, they have to wear two hats and think about what is best [not only] for their own scope but also what is best for the MEP team and the project as a whole. These are not always in alignment. Another BIM manager explains:

> *"as the MEP coordination part goes, it's kind of hard to orchestrate 5 or 6 different trades… it can be kind of challenging, different personalities and everyone has their own agenda or they want to skew things their way but having a little bit of experience in this, you just have to kind of cut to the chase on things and move through it because, you know, yes, we're all concerned about our own trade but eventually you have to get to where everyone shows their finished product and hopefully it all fits in the building and works." (M(S)100805_BFS)*

Photo credit: Assembled Chemical Weapons Alternatives

In the teams we observed, there was at least one person in the group that was the "technologist". This technologist tended to be a detailer who had the technical expertise and experience to utilize BIM tools in interorganizational settings. They may not have been assigned formally as a BIM manager or MEP coordinator, but their knowledge of the tools gave them a social power within the team. In many cases, this person was surrounded by a team of people that did not have the technical aptitude for using BIM tools. BIM knowledge and experience provided the technologist with a degree of social power to leverage within the team. As BIM use becomes more prevalent, the organizational and social advantages that technologists currently experience will diminish somewhat; however, those who maintain a high level of technical knowledge will always have a social advantage. Conversely, we also saw MEP coordinators at a disadvantage when they did not have the technical knowhow required for a BIM manager. It may strengthen MEP coordination to provide a formal technologist to support MEP coordinators who do not have the skills themselves to manage the models.

Our findings reveal a trend towards an emerging role for BIM managers who are in charge of consolidating different configurations of individually authored models.

3.1.3 Participation

The shop drawing detailers are often on the front line of the coordination process. They facilitate the transition from design intent to fabrication and ultimately to field installation. As one mechanical detailer commented:

> *"the buck stops with us, especially within our trade. When I send in the duct work to be fabricated in our shop it comes out and it has my name all over it, you know, I helped design it, I helped detail it, I made sure it fit in the building…" (M(S)100805)*

BIM as a distributed network of models relies on everyone's participation in order leverage it as coordination and optimization tool. Each trade has to rely on the seamless coordination of the network to optimize its own scope of work. As the shared-model approach to BIM becomes more standard on projects, it will be necessary for detailers to include their systems in the model otherwise they risk not being represented in the coordination process. As many respondents commented, "if it's not a model it doesn't exist".

While technical BIM skills will be necessary for detailers, field knowledge is also critical to fully understand how to coordinate and exploit the power of the distributed models. In almost every interview with mechanical contractors and detailers, comments were made about the importance of field experience. The complex and detailed trade-specific knowledge that comes from the field experience of installing MEP systems appears to be invaluable and irreplaceable. Consequently, may of the BIM detailers had field experience prior to their roles as detailers.

Once models are generated, the detailers are most often reassigned to other projects, leaving their models behind them. One risk with the organizational infrastructure of the distributed model is that each model is generated for a specific purpose by the resource that needed it, and its value to that person is in the model's use, not in maintaining the accuracy of the model after the value has been met. A contractor described how the building lives beyond the model, creating a growing gap between model and the as-built conditions, which renders the models useless without proper maintenance.

> *"So all these model components have this sort of half-life that is measured to the point where they no longer become valuable to the author of that component. But the building goes on beyond that, and so we need to be able to take this community of resources and incentivize them to maintain their model components until the completion, so that the assembly of components is representative of the actual building. And filling that gap is going to be a challenge." (B071107)*

At this point the incentives are not in place for specialty contractors to take on the maintenance of the model beyond the building. But as owners demand more accuracy for operations and facilities management, these incentives may be re-structured.

Many uses of BIM have yet to be developed, and all project participants will need to be flexible with whatever uses are developed in the future. Due to the myriad of BIM functions and applications, we contend that the ultimate goals for BIM should not reside in a one-size-fits-all centralized model, but rather in a dynamic, distributed set of models that accommodate project information creation and sharing throughout the process.

3.2 Technology in the Field

New BIM tools and technological advances are pervasive not just in the office where models are detailed, but also out in the field. The latter sometimes referred to as Field BIM. BIM models are becoming increasingly reliable and better suited to adapting to the real time needs of builders in the field. Not surprisingly, these improvements have made possible new opportunities and implications for the tradesmen and women in the field, specifically the need to "build from the model". In the field, new technologies are being implemented to support this trend of mediating the site work with BIM. Since in theory the coordinate space in the model is the basis for the activities in the field, the challenge then becomes to establish effective ways to translate the 3D coordinated information in the model into real 3D space at the job site so that it can be visible, readable, and relevant to builders.

One way in which this is being done in mechanical construction is through the implementation of surveying systems that can project the BIM coordinates into the physical space to perform the layout of hangers and sleeves for MEP trades. The MEP 3D positional data for insert points from the BIM are sent to a total station which then projects the point locations in the field. This is a much more productive and accurate way to do layout. One person is able to manage the total station and can set hundreds of points a day. This takes less labor and time than traditional methods, in which two people would have to painstakingly measure out each insert point location using tape. Laser layout achieves a level of precision and accuracy that is hard to obtain by hand, thus avoiding the rework that is common when using traditional measuring methods.

As one interviewee explained, Field BIM "is trying to make it less complex because you're trying to uncouple all these different components that are related to each other, and relate everything to the grid." On one project we observed, the mechanical contractor employed an ordinate dimensioning system based on xyz coordinates and required that every element placed in that model had x, y, and z coordinates. This rule was carried into the field where everything was measured off the dimensions of the grid instead of the as-built dimensions of the physical building. Everything from the equipment to the walls in the field had corresponding grid points that defined its absolute position. This meant that the elements of the physical building could then be checked back against the grid in the BIM. As one of our respondents put it, "it doesn't do any good if you model, and then you go out and measure off the floor." This is a significant shift in the ways that the trades conceptualize dimensioning and control.

Another trend among BIM projects is an effort to bring the BIM models into the field and into the hands of builders that are physically assembling, installing, and building from the model. This means outfitting the field crew with laptops, tablets, mobile devices, even computer-based projector stations, from which crew members in the field can reference and extract the information they need, as well as see their scope in the context of the other inter-connected systems in order to coordinate activities and problem solve. Projecting an image of the model on a wall at the job site makes the field a digital workspace, where questions can be answered and clashes can be resolved. It is also a communication tool that can offer live updates of any changes or revisions to the BIM models to the builders in the field who are building from them. Decisions about changes to the models and revisions to schedule and layout can be updated in the BIM model and then communicated to the field to provide just-in-time information. This is a vast improvement to the cumbersome process of revising the traditional 2-D building plans. BIM models are dynamic and iterative and they allow a distributed network of trades in the field - connected through laptops or mobile devices– to receive live updates, eliminating information delays and preventing the building off of outdated information as long as the digital information is managed effectively.

As the BIM model moves out into the field and the field crew is expected to engage with and build from the model, the field crew's necessary skill set will require familiarity with mobile computing and some BIM software. Field crew members need to be able to develop new skill sets. They will need to be able to use computers or other mobile devices to the extent of being able to access and navigate the BIM as well as be able to extract the specific types of information they need from the model. It is not unusual to find field crew members without this basic level of computer skills, which could be a hindrance as more and more projects shift towards implementing these technologies in the field. New field crew roles may emerge where specific members are BIM savvy and guide others in the translation from BIM to reality.

3.3 Integrated Design and Construction

As the industry embraces more compressed project schedules there is a simultaneous move to integrate design and construction. This integration is supported by BIM technologies that make problem discovery more visually explicit earlier in the process. As one interviewee explained, subcontractors traditionally come in after design work is completed and "are not used to participating in the process when things are fuzzier, they are used to receiving a set of drawings and then making decisions based upon more or less decisions that have already been made." In the more traditional practices of the past, construction documents were finalized and handed off to the construction team to begin construction work, but with the industry trending to accelerated projects, for most projects the design team is still engaged and the conversations between subcontractors, engineers, owners, designers and general contractors result in ongoing iterations and changes to the construction documents.

These iterations and changes are challenging for subcontractors who need to be able to rely on this information to do their job. BIM tightly couples the subcontractors and the design team technologically, making explicit the series of interdependent subcontractor scope changes that can be associated with a single design change. Yet in many cases the MEP subcontractors remain organizationally divided from the architects and engineers, lacking access to timely information and decisions that enable them to do their job effectively.

There are a couple of different ways to approach these issues. One approach would be to keep design and construction as separate phases, thus maintaining the organizational divisions between MEP subcontractors and the architects and engineers. One of the major implications of this approach is that the detailer's role during construction becomes increasingly difficult. Within this organizational arrangement, detailers engage with the BIM after the design team has done the bulk of the development and may have moved on to other projects in the meantime, making them even less available to answer questions and requests. Detailers may see problems that are made explicit in the model, but may not be able to address them with the architects or engineers because of the absence of organizational channels or lengthy delays as information flows through the RFI channels. With construction happening concurrently, the field crews are not able to build from the BIM, but instead are making decisions based on the reality of the physical building "just to make things fit". The detailers may not have had the opportunity to optimize and coordinate with the level of accuracy they had hoped in their BIM. At times, this can limit the detailers' contributions to the projects' success and demotivate detailers from making suggestions for improvement.

BIM is often used to bridge design intent and field coordination through a constructability review. Much of the time general contractors and MEP contractors find themselves in the position where they need to generate a 3D model from the 2D construction documents. This is because either the design team never constructed a 3D model; constructed one, but isn't sharing it; or has shared it, but the information in the model is unreliable or "for information only". The constructability review is done less as a substitute for standard practices of documentation, and more as an additional tool for coordination and analysis that the building team uses to open communication with the design team and "breathe reality into the concepts" (B081015).

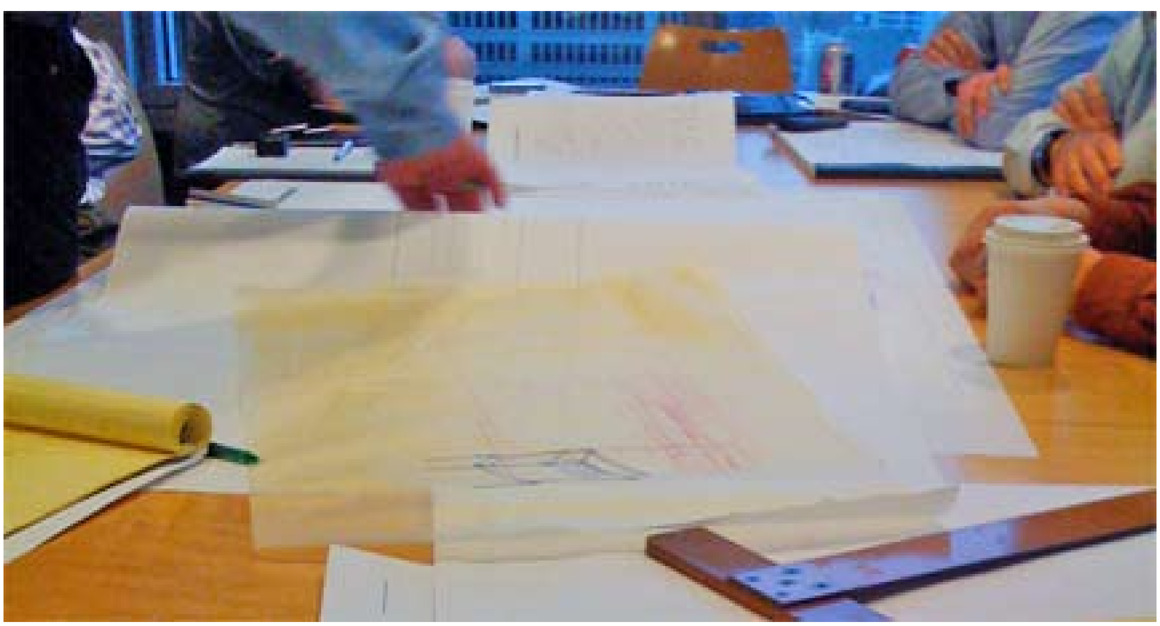
Conversely, another alternative is the trend towards more integrated project organization, where there are open, transparent organizational channels among the subcontractors and the design team earlier in the process. This trend aims to make field knowledge present and explicit in design development. Bringing the mechanical contractor's expertise into the design conversation earlier makes the use of BIM in the construction process more effective. In order to leverage a mechanical contractor's expertise, they should be more tightly connected to the design and decision-making—perhaps integrated into higher levels of project management as a key subcontractor. One blended solution suggested by a mechanical contractor we interviewed has the subcontractors become the draftsmen for the MEP engineers. This potential solution would mean that the mechanical contractor could influence the BIM that is generated in the design development phase to be directly usable, reliable, and relevant for the MEP coordination, fabrication and other construction activities. Given access to these visualizations, labor in the building trades might be able to innovate and solve problems based their knowledge and these details. By providing knowledge related to manufacturing, installation and assembly in the field there is an opportunity to influence the design earlier instead of having a discouraging value engineering phase or a series of time intensive RFIs as the builders review the design later in the process.

In order to build effective integrated teams the potentially competing agendas and conflicting obligations of each project participant need to be considered. Within the infrastructure of these integrated teams, we have identified three often competing obligations of people working in contemporary commercial construction: scope, project, and company. Based on our observations, projects where there was organizational separation among architects, engineers, the general contractor, and the subcontractors there was a culture among the MEP team in which commitment to individual scopes of work often overshadowed their expressed commitment to the project as a whole. When subcontractors and the detailers in particular are left out of the design conversation and are not able to have their own field knowledge represented or considered because of these organizational divisions, they are less likely to feel they have influence in the project and more likely to only feel obligated to their individual scope and not to the project as a whole.

Conflicting obligations are also present at the company level, as different subcontractor companies may prioritize the values of optimizing profits with respect to time across multiple projects. The ability to balance the profit, staffing and resources with an obligation to the completion of the project is one of the places that we found the sharpest conflicts among building design and construction teams.

The company obligation also drives the decisions that project participants make to avoid exposure to risk, which appears to be one of the key obstacles to sharing information in BIM-enabled construction projects. In interviews, structural and mechanical engineers reported that their companies were reluctant to share 3D models with builders because of issues of liability. Issues of ownership, intellectual property, and design liability were all reported as obstacles to sharing BIM models and working collaboratively in BIM.

On the project level there are often unanticipated conflicts between scopes of work in MEP coordination that need to be negotiated. Yet without strong obligations to the project as a whole, it can be difficult to overcome the obligations to individual scope and company. In these settings, individual scopes are often optimized, while the coordination and project-wide optimization are limited. With more integrated practices, these conflicting obligations will still need to be addressed, but the integration itself — empowering detailers and field staff to contribute to the betterment of the



project in the design conversations will go a long way in fostering a focus on project optimization.

In the examples of integrated organizations we have reviewed to date, co-location was an important practice to accompany the co-development of BIM. For example:

> *"we had some pretty good co-location that went hand-in-hand with co-developing a model where we were, during design, during design development, actually, sitting with the architect shoulder to shoulder and everybody, key consultant and key subcontractor was part of that co-location. We didn't have that one magic model that everybody logged into every day, although that would be nice, but we did have a lot of concurrent data being developed and everybody was there to answer questions at any time" (B071012).*

Integrated practice where mechanical contractors enter the design conversations or are co-located with the design team helps to overcome the organizational divisions between decision makers and those who are executing designs.

It is possible that BIM coupled with more integrated teams could support not just the sharing of data, but also a greater sharing of understanding about other work processes and the reasons behind many of the decisions that get translated as data. As one respondent explained, "So the more we can understand the processes of the architect and the engineer and vice versa, the more we can support each other. Like what do you need, what do you think" (E080215_CH). The vision is of integrated teams where builders are "involved earlier, because we want to be a part of that shared understanding and design partners are staying involved later because they can continue to be a part of that shared understanding." It is in this way that BIM can shift "from tool to an enabler of new processes" (B071012).

Photo credit: Assembled Chemical Weapons Alternatives

3.4 Prefabrication

On BIM-enabled construction projects there is a trend towards performing more prefabrication work on projects and larger scale prefabrications. After architectural and structural elements, mechanical and plumbing elements are the most likely to be modeled when using BIM. According to the 2008 Smart market report, mechanical engineers and contractors use BIM to model duct systems, air handlers and major equipment most frequently, while grilles and diffusers are also modeled fairly often by mechanical engineers and contractors (Smart market, 2008). These trends reflect the growing potential for prefabrication using BIM for mechanical contracting. There are several ramifications of this trend for mechanical contracting. Though mechanical contractors have been prefabricating for years, the more extensive uses of BIM are enabling them to scale up the amount of prefabrication performed on projects as well as the size of prefabricated elements. However this expanded use of the model places more pressure on the level of accuracy and detail negotiated in the model among project team members. This has implications for the negotiated boundaries of design, manufacturing and construction.

For many mechanical contractors we interviewed, the building site of the future will be only for installation and assembly, while fabrication will occur in the shop. Prefabrication is a practice that is quite simply more cost effective, reducing business costs associated with having to fabricate elements in the field and support the extra labor and time it takes to do so. For mechanical contractors who have large duct work systems and complex pipe welding to install, prefabrication is a way to achieve higher levels of productivity, spending and wasting less in the field as well as higher levels of accuracy which avoids the cost of rework. Prefabrication reduces the field crew and shifts labor into the fabrication shop. At one fabrication shop we visited the fabrication shop manager showed us a prefabricated steam compressor pipe assembly. He explained that he "could have shipped it to the job site in 60 different parts, but instead we just decided to put it together here." Coupled with its cost-effectiveness, is the improved working conditions of the fabrication shop. The fabrication shop offers a controlled environment compared to the building site, which is always changing and exposed to the

Photo credit: Assembled Chemical Weapons Alternatives

Photo credit: Assembled Chemical Weapons Alternatives

elements. The fabrication shop manager explained that it is better to prefabricate at the shop because they can "inventory material better" and they "have all the equipment that they need". Another fabrication shop manager commented that by creating a shop where all that is being performed is prefabrication, the crew doesn't have to "make small talk with the electricians" or coordinate with other trades what they are going to do each day. "It's like an assembly line here and in the field they wouldn't be able to create an assembly line." For these managers prefabrication allows people to perform their specialized skill set in optimal conditions to achieve higher productivity. As one manager explained "the guys doing the welding, we want them to just weld. Other people can do the pre-assembly work. This means we have higher production."

Prefabrication is growing across the trades with greater use of BIM and shifting practices motivated by BIM. A contractor we interviewed describes this trend:

> *"Bigger subassemblies are showing up, they're fitting faster, now we're able to sort of pre-visualize the path that these assemblies take down the hallways or into the hall or however they go in, before we had to keep them kind of small because we didn't know if they would fit, or they got too big and they didn't fit and now we're in trouble – now we can really, down to the inches clear that corner or something, we can really figure it out and it's enabled us to use more prefabrication, which gives us these sort of factory clean environments and high tolerances, and controlled manufacturing, and just really push that time and quality envelope. We kind of went over this threshold and now we're really exploring just how far can this go. To where even whole racks of pipes are preassembled and just lifted into place and plugged together." (B071107)*

Some BIM tools can send prefabrication information directly to the manufacturing machines in the fabrication shops. The fabrication shops are developing their own systems for inventory and tracking elements in the shop and also once they leave the shop for the site, then tying this information back into the BIM. This trend of connecting the prefabrication and manufacturing process to the BIM is still emerging, but as it does so it blurs the traditional boundaries of manufacturing and construction.

3.4.1 Accuracy, Detail and Timing

BIM for prefabrication requires a high degree of accuracy and level of detail in order for trades to confidently build the prefabricated assemblies from the model. Generating this level of accuracy in the model can be difficult to achieve, either because mechanical contractors are not confident in the reliability of the information that they are building from or they don't have access to the information in time to prefabricate. It may also become unclear who is responsible for this level of accuracy, when it may not necessarily be in the individual scope of the architect or engineer to provide accurate information in the model down to 1/18th of an inch.

Another main theme that emerged from our conversations was timing. One respondent reflected that it is very common that the construction of the physical building happens concurrently with the MEP coordination. He explained that "the GC gets the steel concrete drawings and they don't care. They are building the building…[MEP detailing is] not going to affect their schedule of building the building out." He further pointed out that "the MEP process is longer than building the building" and that "if we wait for 100% buyout, we would be so far behind, so we have to sort of play the game". In order to prefabricate, decisions must be made in advance about installation sequencing, accessibility, timing of deliveries, quantities, and measurements. This requires a detailed schedule to be able to give the fabrication shop time enough to create coordinated detailed shop drawings, order materials, fabricate, and deliver to the site. The more confident teams are in the reliability of the information in the model (since the physical building is not yet created in most cases), the more the teams can use this information to plan other aspects of installation, and the larger the prefabrications can be.

3.4.2 Tolerances and Flexibility

Performing BIM-based prefabrication is enabling new levels of productivity and accuracy, but these developments are also raising new challenges involving building tolerances and flexibility of the systems. Typically, the field crew has techniques to maintain flexibility in the installation process. For example, one respondent recalled that the way they built in flexibility in installing mechanical pumps was to delay screwing any of the pumps into the pads until the last moment, so that they could adjust for variation in the prefabricated spools by moving the pumps on the pads.

Another respondent reflected on the challenges of modeling and manufacturing with precise technologies and then installing prefabricated components within the imperfect reality of the field. He states that construction tolerances are possibly the "biggest challenge we've had." Materials and fabrication are not perfect, nor are construction and installation. However, the BIMs are perfect and accurate and as yet do not incorporate tolerances into the models themselves. The more closely linked BIM is with the field the smaller these tolerances can be. To accommodate and incorporate tolerances into BIM models, builders are starting to use powerful emerging technologies such as laser surveying and laser scanning. With these tools, mechanical contractors collect as-built locations and measurements from the field and bring them into the BIM. Likewise, they can project BIM points onto the physical site. This helps detailers incorporate as-built conditions into the shop drawing models and account for field conditions more accurately and specifically.

3.4.3 Unions

One ramification of having the BIM feed into prefabrication tools is that the modeling is more tightly coupled with fabrication. In some cases, this direct input of information has already eliminated the activity of translation usually associated with this practice in the field. The unions are reacting to this shift and are concerned that now BIM is becoming part of manufacturing. In fact, the sheet metal trade has made detailing part of their union's scope. This has inspired conversations during negotiations around trying to define the boundaries between design, construction, and manufacturing, when these lines are being blurred in practice.

There is much work to be done on both sides to understand the ramifications of BIM technologies and prefabrication techniques for trade union members and their relationships with mechanical contractors specifically and the construction industry more generally. The work is changing and as part of these changes, we anticipate new forms of agreements, training, and perhaps roles that facilitate the creation, coordination and use of BIM and prefabricated work.

Photo credit: Assembled Chemical Weapons Alternatives

As the industry has moved to adapting and adopting BIM, mechanical contractors are the "resident experts" who have used BIM-related tools for some time and consequently have the technical expertise to support project-wide BIM efforts.

Image credit: Student work, ARCH/CM 404

4 Conclusion

Trends and Recommendations

In summary, there are four major trends emerging that will shape the future of mechanical construction.

The **first** trend is the emerging roles for technologists on project teams. Moving towards a BIM process that utilizes a distributed network of models means that technology savvy leadership and management will be needed to effectively steer the process.

The **second** trend is the development of new technologies that link office to field. Pilot projects have begun to use BIM for field installation. Having accurate, detailed, 3D information available to field crew will be a significant source of savings and efficiency, but will entail new challenges and opportunities for field crew members.

The **third** trend is the blurring of design and construction. This trend will continue to lead to more integrated teams and practices and will push more integrated project delivery. However, when integrating teams it is important to consider the conflicting obligations among project participants and to develop organizational and cultural practices that help lessen or overcome these tensions.

The **fourth** trend is the expansion of BIM-enabled prefabrication. BIM is tightly linking design and manufacturing in new ways, shortening field installation time. Mechanical contractors are leaders in this area, and have the opportunity to establish best practices both within their own community and for other specialty trades as well.

Based on our study of best practices and emerging trends within the industry we recommend the following practices to translate our findings into applications among mechanical contractors:

1. Strengthen teams.

Understanding the conflicting obligations of members in the MEP design detailing and installation process is crucial for establishing innovative building projects. Mechanical contractors can bring vital leadership to working with multiple trades, general contractors, architects, engineers, and project stakeholders. Supporting effective teams is one of the key ways that mechanical contractors can lead in the BIM process.

2. Cultivate technology leaders.

Some mechanical contractors have already taken the opportunity to support personnel who emerge as technology leaders. In our case studies and interviews we continue to see people who rise to the challenge of the implementation of new technology both within offices and among the crew. Developing ways to identify or recruit such personnel, develop their skills and retain them will be a key factor for success for mechanical contractors using BIM.

3. Strategize around multiple "BIMs."

The vision of one consolidated model has yet to materialize and we predict, based on our research, that it will not be the primary way that BIM is used. For mechanical contractors this means that separate models will continue to be used for architectural/engineering design and for construction. As the key link between mechanical engineers and builders in the field, mechanical contractors and their personnel (including "detailers") can continue to play a leadership role in the BIM process as models move from design to construction.

4. Design environments not programs.

Our research shows that the social aspects of BIM are critically important to the success of modeling. When implementing BIM technologies consider how the models will be managed, how teams will be run, and how collaboration will be supported. The "people" are as important as the programs in using BIM effectively. Creating an environment that supports BIM and that supports collaboration will pay off.

5. Quantify current practices.

The construction industry should be looking more closely at the trends in technology adoption across the entire spectrum of project professionals, not just across architects, engineers, and general contractors. The industry needs to establish metrics to track the use of BIM and its impact on mechanical contractors and other trade contractors (who are conspicuously absent from the national dialog). The scope of this study did not allow for gathering quantitative data. However, the observations and interview data synthesized in this report offers a preliminary story of the key role mechanical contractors can play in BIM use. Mechanical contractors should call attention to the significant changes to the building coordination process that BIM is causing. We recommend gathering quantitative data to help substantiate and compellingly describe the ways that mechanical contractors are using BIM nationally. Such data could help to further articulate the impact that these changes are having on labor and project management.

6. Remember that technology is an occasion for change.

Several practices outlined in this report could lead to widespread change in the organization of AEC industries. For mechanical contractors to successfully continue to be at the forefront of these changes, they will need to be strategic in how these changes impact their work. New technologies could lead to empowered field personnel who are better able to make installation and construction decisions based on the latest, clearest information Communication among architects, engineers, the general contractor, and mechanical and other specialty contractors could be improved through clearer connections among all project principals. For these changes to occur, strategic change needs to take place in tandem with technological change. Our research shows technology alone does not drive change, but it can be an opportunity and can enable change.

Resources

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Image credit: Student work, ARCH/CM 404

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