Prefabrication and Building Information Modeling is the future in Canadian construction. Prefabrication in Europe and Asia is far ahead of our current construction model in Canada. The trend and demand for prefabrication, especially for out of town work, is expected to become a driving force in Canadian construction. To remain ahead of this trend, Division 15 Mechanical Ltd. has enhanced our way of doing business. With the optimization of Building Information Modeling (BIM) for mechanical systems, it is now significantly easier and more efficient to translate building design into components.

BIM allows us the luxury of being proactive with identifying and resolving issues before they become an obstacle at the construction site. BIM minimizes the risk of costly mistakes and eliminates time of as-built drawings development and documentation. BIM also benefits our clients by minimizing delays, reducing the number of change orders, better end installation results, and high quality as-build drawings.

Our strategic Plan to adopt BIM came from top management in 2010 following two events: first was a seminar in which BIM and its benefits presented. Second, and the most important, was the loss of a major international project to a mechanical contractor with extensive pre-fabrication capabilities. For Div. 15’s two founding principles, BIM was a way to “get ahead of the curve” and “gain a distinct competitive advantage over other mechanical contractors”. Strategically speaking, the adaptation of BIM aligned itself with Div. 15’s organizational strategy that considered three key elements:
(1) Increase visibility and market-share within the mechanical contracting domain.
(2) Focus on design-build and design-assist type projects and
(3) Increase quality and productivity through modeling and pre-fabrication.
More specifically, the motivations behind the adoption and implementation of BIM were three-fold:
• To create interference models for self-performed clash-detection and coordination with their sub-trades and fabricators;
• To minimize loss of productivity in the field due to rework;
• To pre-fabricate elements and minimize on-site fabrication in order to increase productivity and quality of work;
• To enhance our ability to perform out of town work.

Division 15 Mechanical have invested three years in building this infrastructure to the point where we are now enjoying the benefits of our investments. As more and more General Contractors change their focus to prefabrication, Division 15’s forward thinking has positioned us well to synchronize our system to that of many prefabricated building systems.
Pilot Project III: BIM Adoption and Implementation Within a Specialty Contracting Firm
# Table of Contents

1. Introduction ................................................................................................................................. 1
   1.1. Summary of Research Findings .............................................................................................. 1

2. The Organizational Perspective ........................................................................................................ 3
   2.1. Organizational context ............................................................................................................. 3
   2.2. The decision to BIM ................................................................................................................. 3
   2.3. Setting Goals ............................................................................................................................ 4
   2.4. Adopting and implementing the technology .............................................................................. 4
   2.5. Restructuring the Organization ............................................................................................... 6
   2.6. Transforming their Processes .................................................................................................... 7
   2.7. Summary .................................................................................................................................. 8

3. The Project Supply Chain Perspective .............................................................................................. 9
   3.1. Project delivery context ............................................................................................................ 10
   3.2. Project based evolution ............................................................................................................ 11
      3.2.1. Project 1: Large Institutional District Energy Project *(the pilot project)* .................. 11
      3.2.2. Project 2: Medium 2-storey Institutional Healthcare Building *(increased coordination at the supply chain level)* ................................................................. 15
      3.2.3. Project 3: Medium-size Municipal District Energy Project *(towards pre-fabrication)* .......................................................... 17
      3.2.4. Project 4: Renovation of a Large Commercial Building *(increasing interaction within the supply chain through BIM)* ........................................................................... 18
   3.3. Summary .................................................................................................................................. 19

4. Assessing and evaluating the impact of BIM .................................................................................... 20
   4.1. Assessment and evaluation process ......................................................................................... 20
   4.2. The impact of BIM .................................................................................................................... 21
      4.2.1. Perceived impact: the qualitative perspective ................................................................. 22
      4.2.2. Measured impact: the quantitative perspective ............................................................... 24
   4.3. Organizational Assessment Matrix .......................................................................................... 25

5. Discussion ....................................................................................................................................... 27
   5.1. Challenges ................................................................................................................................. 27
   5.2. Lessons learned ....................................................................................................................... 29
6 Conclusion ........................................................................................................................................... 31
7 Acknowledgments ............................................................................................................................... 32
8 References ........................................................................................................................................ 32
Appendix 1: Research setting .............................................................................................................. 33
Appendix 2: Project delivery process ................................................................................................ 36
Appendix 3: Proposed performance metrics ...................................................................................... 45
Appendix 4: CSCE Paper- BIM adoption and implementation within a mechanical contracting firm .......................................................................................................................... 48
1 Introduction

This report presents the Building Information Modeling (BIM) adoption and implementation process from a specialty contractor’s perspective. The organization studied is Division 15 Mechanical Ltd (Div. 15), a mechanical contractor based in Vancouver, BC specializing in the commercial and institutional construction sectors. Div. 15 decided to adopt and implement BIM in 2010, thus putting in motion a process that would transform how they operate as well as how they interact with the remainder of the project supply chain. This report describes this transformation at the organizational level within Div. 15, and at the supply chain level throughout several projects.

Although many case studies have been written about BIM implementation, particularly in the United States, very few have focused on the specialty contractor perspective, particularly small and medium enterprises (SME) that have less than 50 employees. For these types of organizations, it is more difficult to acquire the necessary software technologies and to transform their organizational practices to take advantage of this new way of working. Many have worried that SME’s might not be able to keep pace with the rate of change and adapt accordingly. This research on the Div. 15 organization demonstrates that even small enterprises can reap significant benefits from BIM when they are strategic and thorough in planning out their adoption process.

The approach taken by Div. 15 to develop a strategic implementation plan provides an excellent model for organizations seeking to make this change. Of particular importance was the combination of a top-down and bottom-up approach to BIM implementation. In combination with a clear vision and realistic goals, this approach enabled them to align their organizational strategy with the BIM adoption and implementation effort. Also important was their focus on BIM implementation at both the organizational and at the project level.

We studied Div. 15 over a ten month period with a focus on the following research objectives:
- Document the BIM adoption and implementation process for a specialty contractor in the AEC industry from an organizational and project supply chain perspective;
- Evaluate the impact of this transformational process within the organization and across the organization’s project network;
- Determine avenues of development for productivity gains using BIM and other IT tools.

This report is organized as follows. First, the BIM adoption and implementation process is presented from the organizational perspective. Next, the BIM adoption and implementation process at the project supply chain level is described. Then, the process developed to assess and evaluate the impact of this transformational process is described. Next, our findings on the perceived and measured impact of BIM are presented. Finally, the lessons learned of the research project are discussed.

1.1 Summary of Research Findings

BIM facilitated the following benefits for DIV 15:
• Increased visualization, coordination and validation capabilities
• Increased opportunity to offer additional services and added value to clients
• Increase in requests for proposals and invitation to bid on larger projects
• Increased leadership within the supply chain
• Increase in overall client satisfaction
• Better conformance to original project scope and intent
• Increased quality of communication and information flow
• Increase in personnel productivity
• Increase in budget conformance
• Increase in information accuracy
• Increase in prefabrication efficiency

The main challenges encountered by Div 15 in their adoption process were:
• The project setting which limits the opportunities to implement BIM.
• Inconsistency in the deployment of BIM at the project level which influences the extent of the use of BIM
• Lack of control and influence on the project delivery method which results in a reactionary approach to BIM implementation at the project level.
• Hiring and maintaining personnel with adequate modeling and coordination capacity
• Choosing the appropriate software suite and managing technology
• Garnering an adequate understanding of the transformational process at the organizational level
• Evaluating ROI at the organizational level and the project level

The main lessons learned were:
• The importance of a consistent and coherent organizational strategy in the BIM adoption and implementation process.
• The opportunity for a speciality contractor to isolate the BIM adoption and implementation process
• The necessity to strike a balance between a top-down and bottom-up adoption approach and the creation of a steering committee with sufficient decisional power
• The importance of an agile approach to the transformational process
• The importance of establishing the Suitability of BIM within the organization: Is BIM right for the organization?
• The importance of including all stakeholders at the organizational level in the adoption and implementation process.
• The importance of establishing clear uses and requirements for the model
• The need to assess and evaluate the impact of BIM
2 The Organizational Perspective

The first perspective is that of the organization itself. The process behind the BIM adoption and implementation effort as well as the transformation required to the organization's internal structures and workflows are presented along three inter-related dimension: the technology dimension, the organizational dimension and the procedural dimension.

2.1 Organizational context

Division 15 Mechanical Ltd. was founded in 2004 and counts 50 employees deployed along a project-based organizational structure across two divisions: 13 office based employees (project managers, coordinators, estimators as well as administrative staff) who form the project management team and 37 site based employees (superintendents, foremen, journeymen). Since their foundation, they have completed over 50 projects ranging in value from $100k to $12M.

2.2 The decision to BIM

The decision to adopt BIM came from top management in 2010 following two events: first was a seminar in which BIM and its benefits were presented. Second, and most important, was the loss of a major international project to a mechanical contractor with extensive pre-fabrication capabilities. For Div 15’s two founding principals, BIM was a way to “get ahead of the curve” and “gain a distinct competitive advantage over other mechanical contractors”. Strategically speaking, the adoption of BIM aligned itself with Div. 15’s organizational strategy which considered three key elements: (1) Increase visibility and market-share within the mechanical contracting domain (2) Focus on design-build and design-assist type projects and (3) increase quality and productivity through modeling and pre-fabrication. More specifically, the motivations behind the adoption and implementation of BIM were three-fold:

- To create interference models for self-performed clash-detection and coordination with their sub-trades and fabricators;
- To minimize loss of productivity in the field due to rework;
- To pre-fabricate elements and minimize on-site fabrication in order to increase productivity and quality of work.

While the initial impulse for this transition towards BIM came from the top management, the adoption effort itself came from the user base, denoting a balance between a top-down and a bottom-up approach to the BIM adoption process. A dialogue between management and the employees was facilitated through the creation of a committee to help steer the BIM adoption effort. The committee’s mission was to set a clear vision and establish goals and objectives which would dictate the implementation plan. They also headed the BIM adoption effort by reviewing and selecting the appropriate software and hardware packages and by implementing BIM in a pilot project. Thus, a substantial part of the decision making process was delegated to the personnel that would be using BIM which allowed them more latitude and input in exploring other avenues such as robotic stations and laser scanning. An important characteristic of the BIM committee which was observed was that it possessed sufficient power to actually make decisions and implement the strategies that were put forth.
2.3 Setting Goals

The goals set by the steering committee for the BIM adoption and implementation process are incremental. The short term goals involve the actual adoption and implementation of BIM while the longer term goals involve an overall strategic approach to improving productivity in the field through increased use of technology and pre-fabrication. More specifically, these goals are:

1. **Short Term Goals:**
   i. Obtain additional modeling software licenses.
   ii. Train additional personnel on the modeling software
   iii. Revisit detailing software purchase & training.
   iv. Obtain/Implement use of Robotic stations for field layout.
   v. Design/Implement a BIM Library management strategy.

2. **Medium Term Goals:**
   i. Develop spool drawing capability for pipe prefabrication.
   ii. Set up pipe fabrication shop in new building:
      a. Weld pipe fabrication line
      b. Grooved pipe fabrication line
      c. Small bore pipe fabrication line
      d. Overhead crane
   iii. Truck, trailer, forklift for material shipment to sites

3. **Long Term Goals:**
   i. Phase in robotic stations on pipe fabrication lines
   ii. Phase in packaging systems for out of town shipment

Over the course of the research project, additional goals were introduced, notably:

- Ease information flows between site and office personnel through the development of mobile computing capabilities;
- Develop parallel modeling capabilities (such as laser scanning) to offer added value to clients;

To begin accomplishing these goals, it was necessary for the committee to: set a course of action; determine a timeline; plan and allocated the appropriate resources; and communicate the vision, objectives and goals throughout the organization. To do so, a detailed budget was created and a timeline developed dictating the manner in which these goals would be attained. A BIM guide has also been developed in which the overall approach to BIM is presented and the specifics of the adoption and implementation process are dictated. This guide is ever evolving and was used to capture and diffuse the knowledge and experience with BIM acquired by the organization.

2.4 Adopting and implementing the technology

The choice of the BIM software represents a major commitment due to subsequent issues such
as suitability, interoperability, training and support. In the case of Div. 15, the BIM committee evaluated and studied multiple BIM tools available on the market extensively. After more than a year of evaluation, the company chose a particular modeling software platform for the following reasons:

- The AEC industry (in North America) is moving towards massively implementing this software platform;
- The clients who are turning to BIM are adopting this software platform;
- Product models and libraries are the most extensive of any available software;
- On-line support, user groups and communities are the most extensive of any available software.

However, the committee did have to compromise in their decision as the chosen tool had limitations, such as:

- Level of detail: The chosen software platform was not a fabrication level tool, wherein the achievable level of detail is insufficient for fabrication purposes.
- Bill of material and spool sheet automation: As per the first point, the modeling software platform is not geared towards fabrication and specifically mechanical element fabrication.
- Library management: Probably the most critical aspect of the chosen software platform is the lack of a clear library management system within the modeling program. Due to ever-evolving equipment and elements in the MEP field as well as an ever increasing quantity of available digital components, management of the digital information components that are inserted into the model is rendered very difficult. The modellers require up-to-date and precise components that reflect the specifications of a project if they are to produce fully integrated information models.

While the modeling software allows the organization a better-integrated workflow with other consultants and contractors due to increased interoperability, a second piece of software had to be introduced in late 2012 in order to overcome the severe limitations of the modeling software in respect to fabrication level detailing (hereby the detailing software). This software platform is geared towards fabrication and contains a 3rd party library of elements, which is managed externally.

The choice of software had an impact due to its usability and the extent of allowable diffusion of information. The organization had to implement two different pieces of software in order to interact with other members of the project team while providing the right amount of detail for fabrication. The question of interoperability between both pieces of software has not yet fully been resolved and a substantial amount of work has to be done when transacting between both pieces of software. This increases cost associated to the modeling and detailing component of a project. However, it was noted that the organization did have a realistic view of what they were investing in and could react and adjust their strategy to fit the different capabilities of the various software tools implemented.

In terms of financial impact, the total costs for the BIM technologies specifically represent 0.78% of the organization’s average yearly sales volume. These costs include:

- Software licenses (2 modeling software licenses and 1 detailing software license)
- Hardware upgrades
• Training
• Salaries and burden for BIM personnel

These costs were in addition to the existing costs related to the IT infrastructure including the network and maintenance.

2.5 Restructuring the Organization

Within Div. 15, the transition to BIM is transforming the way in which project teams are structuring themselves to cope with the new roles and responsibilities introduced by this transition. The transformation of Div 15’s internal structure is in part due to the creation of the BIM manager and BIM coordinator roles as well as the creation of the BIM steering committee. The BIM manager’s responsibilities include, among others:

• Testing and updating the various software solutions,
• Creating and maintaining the organization’s BIM guidelines,
• Object library management,
• Exploratory searches to further BIM capabilities such as laser scanning,
• Participation in the initial set-up of a project’s BIM project execution plan

The BIM coordinator’s responsibilities include, among others:

• Model creation and maintenance on a project basis
• Coordination of day-to-day project activities involving the information found within the model
• Coordination of models with IFC drawings and as-built conditions
• Creation of fabrication details packages for diffusion of information to site
• Coordination of model with sub-trades and consultants including clash detection
• Flagging of conflicts and clashes and initiation of the resolution loop

Both these roles are completely new to the organization and require a specialized skill set. Div. 15 initially trained two people, one office employee who would become the main BIM manager and coordinator and one site employee, a project foreman. As BIM manager/coordinator, they chose to hire a person that would be dedicated to the BIM implementation process and train this person accordingly. In terms of field personnel, initially, the aim of the organization was to educate and inform their personnel on the scope of BIM, the possibilities it offers and the way in which their work would be affected by this transition. While field personnel were not specifically being trained to use the modeling/computer based tools, they were being informed on what the technology and the shift in processes meant for them. Further personnel would come from in-house staff and be trained according to the need on a project-by-project basis. The firm is therefore looking to take advantage of an increase in BIM projects to educate and train additional personnel and diffuse lessons learned throughout the organization through their BIM guide.

The doubling of the project coordinator role within a project team also had a major impact on internal structures and project execution. In addition to the original project coordinator, who’s role is to manage the day-to-day information flow within the project team, the role of BIM coordinator appears due to the modeling and model coordination requirements introduced by BIM. Ideally, the same person would fill both roles, however, time constraints and capability issues have made it difficult to do so thus far. Furthermore, it is questionable whether both roles
will be completely integrated in the near future due to the sheer effort needed to accomplish both tasks on any considerable job. This will require a complete reconfiguration of information flows towards a completely model-based workflow (i.e. all documentation is managed with the model through a third party platform).

The transition to BIM is similarly transforming the organization’s external structure through the addition of BIM centric roles and modifications to responsibilities. However, it is becoming apparent that the external project environment (i.e. procurement method, contractual relations, etc.) will heavily influence the extent of this transformation at the project supply chain level. In this case, BIM wasn’t seen as the major disruptive force. Rather the environment or context was instead seen to influence the role of BIM within the supply chain. In turn, this will largely dictate the extent to which BIM will be used within the supply chain.

2.6 Transforming their Processes

The adoption and implementation of BIM is seen to be transforming the process dimension to a large extent. Decisions in both the technology and the organization dimensions are having major repercussions in the process dimension. Furthermore, both internal and external processes are being disrupted to suit a project environment where BIM is implemented.

For the organization, the transformation of internal workflows due to BIM has been two-fold: First, the need to develop in-house modeling capabilities where previous modeling capabilities were non-existent. Company standards and templates had to be equally developed. Second, the information and workflows between office and field personnel needed to be redefined. Traditionally detailed execution has been resolved in the field through trial and error. The introduction of BIM has shifted this resolution process to the office. In parallel, ensuring that the information produced in the office gets to the field and distributed to the field workers in an efficient manner is a priority for the organization. Where traditionally, the site foreman would have dissected and dispatched the various pieces of the contractual drawings to specific workers through face-to-face discussion and the use of hand sketches, now the information is being produced in the office and being communicated through more precise fabrication drawings.

While information flowing from the office is becoming much more precise and reliable, the expertise of the field workers is now lacking in the resolution process. Therefore a communication protocol to transfer and diffuse information is a must in order to encourage some feedback flows between the office personnel and the field personnel, notably the BIM coordinator and the site foreman. In order to put this protocol in place, there must be a clear understanding of what information is needed downstream. Also how the information is communicated must be determined. Ultimately, the process through which plans are analyzed, models built and validated and finally documentation produced and distributed must be laid out and formalized.

It is expected that the way in which a project team interacts and collaborates will largely be transformed by the use of BIM. However, having yet had the chance to participate in a fully collaborative BIM endeavor, the transformation of Div 15’s external workflows has been relatively limited. As illustrated by project #2 discussed below, the use of BIM in a project setting has allowed the organization to take a more predominant role within the project team. However this is not uniquely attributable to BIM but also to the procurement method, which allows the organization to have better control over project execution from early on in the design stage.
Therefore there is a discernible tension between the use of BIM and the project environment whereby the project environment will dictate the use of BIM and the use of BIM will impact the project environment.

To date, Div.15 has performed almost all of the modeling in house, namely the creation of spool drawings and coordination of specific problem areas. As the extent to which BIM is implemented within the project team increases, it is expected that Div 15’s role will shift from model creator to model integrator. This is the case in project #4, discussed below, where BIM requirements were included in the contractual documents for the sub-trades whereby the trades had to model their scope of work and provide this model to Div.15. In turn, Div. 15 modeled their self-performed scope of work and coordinated all the models together.

2.7 Summary

From an organizational perspective, the following elements were determinant in the BIM adoption and implementation process, illustrated in Error! Reference source not found.:

- Commitment to the transformational process
- Buy-in from top management and the user base
- Alignment of the organizational strategy with the BIM adoption and implementation effort
- Establishment and communication of a clear vision for BIM throughout the organization
- Creation of a BIM steering committee
- Setting of clear, attainable and measurable goals and objectives
- Identification and empowerment of BIM champions within the organization
- Empowerment of the user base with the capacity for input into the decision making process
- Increased agility in dealing with the consequences of the transition to BIM (such as managing training and down-time of BIM capable personnel as well as redefined workflows)
- Thorough review of BIM software informing a choice of suitable software to commit to.
- Allocating sufficient resources
3 The Project Supply Chain Perspective

The second perspective is that of the project supply chain. While a clear organizational strategy is seen as key to the BIM adoption and implementation process, the project supply chain will largely influence the extent to which the organization can put that process in motion.
3.1 Project delivery context

Div. 15 perform most of its work in the medium to large commercial and institutional sectors. In trying to establish relationships with it’s client base, Div. 15 caters mostly to larger institutional owners, private owners and larger general contractors (GC) in the Vancouver/Lower-Mainland area. They have a relational philosophy by which they aim to develop strong ties with a small number of GCs in order to get repeat business instead of bidding on all projects that are out to tender at anytime. They are intent on developing a reputation as an “added value” contractor and wish to work with clients who have the same philosophy and “know how to perform”.

Div. 15 delivers projects concurrently across two project streams. Project stream #1 involves the delivery of District Energy projects including fabrication and installation of Energy Transfer Stations (ETS) otherwise known as district energy projects. Project stream #2 involves the delivery of traditional building mechanical systems including HVAC, fire protection, plumbing, etc. Within both project streams, the organization will typically sub-contract all sheet metal and ducting work, fire protection, pipe insulation and refrigeration while plumbing, HVAC piping and equipment installation will generally be self-performed work.

Div. 15 typically acts as Prime contractor in project stream #1 (district energy projects) which allows them to deal directly with the client and the consultants. This translates to substantial control over the construction supply chain. Typically, district energy projects are commissioned by larger institutional or governmental clients and are one-off, capital works, which are performed on a very large scale but are non-repeat markets. This mostly results in a design-bid-build procurement method, with the well-known challenges that this type of procurement route involves, namely fragmentation of design and construction. Div.15 have performed many projects in this stream and have thus developed an expertise in this type of project. The repetitive nature of these types of projects, the relatively small scale of modeling required, as well as the organization’s scope of self-performed work make this type of project ideal for BIM. In fact, the organization took advantage of this by utilizing project #1 as a pilot project for the adoption and implementation of BIM within the organization. This allowed the project team, and on a larger scale the organization, to develop the basic modeling skills necessary, and to manage the redefinition of their internal workflows whilst delivering the project without too much disruption to project delivery. As the organization continues to evolve within this project stream, they are furthering their modeling skills while slowly developing their detailing and off-site pre-fabrication capabilities.

Within project stream #2, procurement methods and project delivery processes become more varied, from traditional design-bid-build to a more integrated approach such as design-build. Division 15 largely favors design-build projects as this allows them to be more intimately involved at the onset of the project and develop better relationships with the consultants and the general contractors whilst increasing control over project delivery. For projects within this stream, the relationship will typically be with the GC, since it is the GC that will hire and transact with Div. 15. This work is typically commissioned by private owners who in turn hire Construction Managers/GCs to perform work thus allowing a more relational approach to project formation. This project stream also presents the opportunity for a more intense collaboration through the co-development of the BIM with the consultants and other trades. However, to date, this has not been the case as the organization has only been able to deploy BIM in a lonely setting, due to a general lack of BIM requirements on projects in the Vancouver market.
3.2 Project based evolution

While the organization have set a clear path in the BIM adoption and implementation process, it remains that its execution is heavily reliant on the opportunities for BIM offered by the various project environments in which the organization is involved. In other words, while the organization is well equipped to transition to BIM, the heavy reliance on the project-based nature of the AEC industry means that the rate of BIM implementation is being modulated by an external source, on which the organization has little or no control. This means that the organizational strategy towards BIM implementation must take into account the project supply chain perspective. In response to this, the organization has adopted a “triggering” process by which specific projects are targeted to incrementally develop BIM capabilities while maintaining the over-arching strategy towards BIM developed by the steering committee (Figure 2).

**Figure 2 - Project Based Evolution**
3.2.1 Project 1: Large Institutional District Energy Project (the pilot project)

Project #1 consisted in phase 1 of the replacement of a district energy system on a large institutional campus. In this case, work was being performed within existing buildings and had to be retrofit amongst existing equipment. The work was segmented into two packages, campus-wide distribution (DPS-primary distribution) and the installation of energy-transfer station (ETS-secondary distribution). There were 8 different ETS to fabricate and install within 8 different buildings located on the campus. The organization was acting as a Prime contractor and the project was procured in a traditional design-bid-build mode. Overall project cost for the ETS portion of this project was approximately $970,000 and this portion of the project was completed in a little over 10 months. Overall costs associated with BIM for this project, namely the time spent on modeling and coordinating with the fabricators, represented 4.1% of total project cost. Very little in terms of contractual BIM requirements were mentioned in the contractual documents, with the client asking for a “taste” of BIM, without specifying exact requirements.

All handoffs between consultants and contractors were paper-based, mainly 2D drawings with limited isometric sketches (Figure 3). Therefore all modeling had to be performed directly by the organization itself. Being mainly underground piping, the primary distribution was deemed unnecessary to model, as doing so would provide no added
value. In contrast, the secondary distribution (ETS) was seen as offering potential for minimizing waste through conflict resolution and pre-fabrication. Therefore, the organization had their BIM coordinator model all 8 ETS from the 2D contractual drawings (Figure 4 - Figure 5). For certain areas deemed problematic, the mechanical rooms were laser scanned and included within the model (Figure 6). This allowed the project team to resolve most issues prior to installation, validate the design and have the field workers prefabricate certain elements for easier installation.

As this was the first BIM project for the firm, considerable adjustment was required in order to successfully benefit from the models being produced. Most importantly was how the information produced in the office would get to the field and distributed to the field workers. In terms of benefits, the capacity to resolve most issues relating to installation prior to actual fieldwork is difficult to quantify. To quote one interviewee: “[This project] would have basically been impossible to build without the use of BIM […]” meaning that the organization had a lot to lose in this project if something went wrong.

3.2.1.1 Project 1 summary:

1. BIM uses:
   a. Basic modeling of 8 energy transfer stations (ETS)
   b. Clash detection within existing mechanical rooms through laser scanning
   c. Intuitively established the first version of a communication protocol between the field and the office for fabrication drawings
   d. Creation of fabrication level drawings from 2D IFC drawings with accurate and precise measurements

2. Capabilities developed
   a. Initial modeling capabilities
   b. Laser scanning capabilities
   c. Information dissemination between office and field

3. Main benefits and opportunities
   a. Substantial scope of self performed work allowed to reap direct benefits from the modeling process
   b. Minimized loss due to upstream conflict resolution
c. Rapid resolution of issues due to easy visualization
d. Project "would of almost been impossible without BIM"
e. Increased reliability ad accuracy of information sent to site

4. Main Barriers
   a. No previous in-house modeling capabilities
   b. Traditional D-B-B project results in little interaction with design professionals
   c. Paper based hand-offs and models provided by consultants were inaccurate and could not be used for fabrication purposes.
   d. Level of detail offered by modeling software was insufficient to communicate all information necessary for prefabrication (information had to be supplemented through other means)

Figure 6 - Design Validation
3.2.2 Project 2: Medium 2-storey Institutional Healthcare Building (*increased coordination at the supply chain level*)

Project 2 involved the new construction of a wood-framed, institutional health-care building. No BIM requirements were developed in the contracts and thus Div 15 was the only member of the project team that decided to model the project and deploy BIM to assist in the design and delivery process. The project was a design-build project, which meant that the firm hired the mechanical and plumbing engineers as consultants. Also under the responsibility of the firm were the sheet metal contractor, the fire protection contractor, pipe insulation and refrigeration contractor while plumbing and equipment installation were self-performed work. Project coordination was largely done through 2D drawings, with the exception of Div 15 who produced a BIM model. In this case, the project team modeled solely the spaces that were deemed to be problematic such as mechanical rooms and ceiling spaces. Overall project cost for the mechanical portion was approximately $1.0 million. Overall costs associated with BIM for this project represented 0.93% of total project cost.

The major difficulty faced in this project was the general reluctance by the project team to move towards BIM. Div. 15 thus worked in a lonely setting, developing their own model and holding all their sub-contractors accountable to that model. This was possible since the firm held the contracts with the sub-trades. However, the firm also modeled elements, which were outside their scope of work, such as electrical trays, in order to coordinate and perform clash detection. When presented with the model, the electrical contractor refused to comply with the installation strategy set-forth by the firm, which caused serious problems as ceiling space was at a premium for this project. The lack of control over other disciplines could be viewed as a lack of contractual control and/or a basic lack of good faith. Even though the delivery method was more integrated, being a design-build, there were still no provisions in the contract that prevented siloed work and individualistic attitudes. In this case, while BIM was beneficial to a certain extent, it is possible to see that the contractual considerations were not providing the necessary environment to facilitate collaboration.

In terms of benefits, again the visualization capabilities were highly used and beneficial. As previously stated, ceiling space was at a premium, so much so that once the initial model was created by Div. 15, they noticed that many services indicated in the 2D drawings produced by the consultants would simply not fit (Figure 7). Therefore, they had to redesign certain elements and when that did not work out, they ultimately had to ask the design team to reconsider the structure in certain areas. The design team, presented with the irrefutable visual evidence that the current structure and mechanical scheme could not work together, they re-designed the problematic areas to offer the clearance required. This was done during the design stage and was possible due to the firm’s modeling effort. The impact of this is difficult to quantify, but needless to say, had the issue not been raised during the design stage, the entire project could have been compromised.
3.2.2.1 Project 2 summary:

1. BIM uses:
   a. Modeled all areas with most potential for conflict (shafts, ceiling spaces, etc.)
   b. Decided to model all building services within those areas (HVAC, Fire Protection, Plumbing, Electrical, etc.) to perform clash detection
   c. Used for clash detection and coordination of mechanical elements in specific areas.

2. Capabilities developed
   a. Increased modeling capabilities
   b. Communication of layout, assemblies and sequences to other disciplines for coordination
   c. Improved information flow to site

3. Main benefits and opportunities
   a. Allowed the firm increased leadership in the project supply chain
   b. Deployment of BIM in a design-build role allowed more input at the design stage and feedback through model visualization
c. Visualization capabilities allowed to prove beyond a doubt that certain structural elements had to be redesigned for the mechanical systems to work prior to construction which potentially saved considerable amounts of time and money.

4. Main Barriers
   a. BIM deployed in a ‘lonely’ setting
   b. Contractual set-up not geared towards collaborative work and use of BIM
   c. Not all specialty contractors on board with the use of BIM
   d. Model lacking meta-data, used primarily for visualization purposes

3.2.3 Project 3: Medium-size Municipal District Energy Project (towards pre-fabrication)

Similar in nature to project #1, project #3 consisted in the second phase of the construction of a district energy project including distribution piping and energy-transfer stations within a new development located in the Vancouver core. While no BIM requirements were developed in the contractual documents the organization used this project to further their detailing and pre-fabricating capabilities. Thus, the detailing software was implemented and its capabilities further explored. In terms of pre-fabrication, off-site pre-fabrication capabilities were limited due to the shop not yet being fully functional. However, highly detailed spool drawings were issued to the site and an on-site pre-fabrication area was set up where many elements were fabricated prior to installation within the mechanical rooms. As in project #1, most handoffs between consultants and contractors were paper-based, mainly 2D drawings with limited isometric sketches. The models that were handed over to the organization were inaccurate and unsuitable for construction purposes. They also were issued “for information only” which immediately results in a lack of trust in the model by the BIM coordinator for the mechanical contractor. Therefore all modeling had to be performed by the organization itself. With the introduction of the detailing software, an additional step in the workflow was introduced whereby the model was created in the modeling software from the 2D drawings and then transferred to the detailing software once issues where worked-out. The output from the detailing software provides highly detailed spool drawings, which are suitable for fabrication contrary to the modeling software, which has limited capabilities in that respect.

Div. 15 intends that all future projects in this stream be entirely pre-fabricated off-site in the shop and shipped to site. In existing environments, such as project 1, a laser scan of the environment will be performed in order to allow design validation prior to project execution.

3.2.3.1 Project 3 summary:

1. BIM uses:
   a. Used BIM to model and detail four Energy Transfer Stations
   b. Increased level of detail included in the model for off-site pre-fabrication

2. Capabilities developed
   a. Building on experience acquired during Project #1
   b. Refined communication protocols to get information to field
   c. Developing an expertise in the field of modeling Energy Transfer Stations
   d. Experimenting with tablets in the field

3. Main benefits and opportunities
a. Modeling and fabrication of Energy Transfer Stations is becoming streamlined

4. Main Barriers
   a. Traditional D-B-B project results in little interaction with design professionals
   b. Learning curve with initial deployment of detailing software

3.2.4 Project 4: Renovation of a Large Commercial Building (increasing interaction within the supply chain through BIM)

At the time of writing the report, Project 4 had just begun. The project involved the major renovation of a mixed-used building in downtown Vancouver. This was a design-assist procurement method for Div. 15 who was hired by the GC working in a Construction Management (CM) setting. In this case, Div. 15’s BIM capabilities did play a role in obtaining the contract as the GC was looking for BIM capable sub-contractors. Minimal BIM requirements were developed in the contracts with both the general contractor and the client. The consultant team created a BIM, however it was not brought to a high level of development (LOD) as the contractual requirements did not ask for a specific level of development be attained. However, during the project, the client requested that an as-built model be handed over for building operations and maintenance at the commissioning phase. This project represents the first case where Div. 15 included specific BIM requirements in their own contractual documents for the procurement of their sub-trades, namely the HVAC and fire protection trades who were expected to produce models.

Figure 8 - Model Based Detailing
This project represents the first BIM based design-assist project. From the firm’s perspective, it was expected that BIM would be used to coordinate the mechanical rooms, mechanical shafts and other areas deemed problematic. While there is insufficient data to paint a full picture as the project is not yet fully under-way, the organization was looking towards acquiring a laser scanner to further develop their skills with these tools. More importantly, they had marked this project as a trigger to acquire robotic stations for the installation of elements such as hangers and sleeves. They were also looking to deploy tablets on a larger scale for the site foreman as well as project coordinator.

3.2.4.1 Project 4 summary:

1. BIM uses:
   c. First deployment of BIM in a collaborative setting
   d. Use BIM to model all areas with most potential for conflict (shafts, ceiling spaces, etc.)
   e. Clash detection, visualization and coordination

5. Capabilities developed
   a. Acquiring laser scanner and further developing laser scanning capabilities
   b. Building on the expertise of project #2
   c. Developing capacity to collaborate through BIM within project network
   d. Implementing Robotic Stations and Tablets in the field

6. Main benefits and opportunities
   a. Benefits expected to align with publicized benefits (fewer RFIs, better cost control, high quality work, etc.)
   b. Creation of fabrication level models will translate to highly detailed as-built drawings for the client

7. Main Barriers
   a. Unclear modeling requirements from the client/owner
   b. Need for additional staff to be trained due to increasing BIM workload
   c. Lack of experience in a collaborative setting
   d. Need to align standards with others in the project network

3.3 Summary

From a project supply chain perspective, the following elements were determinant in the BIM adoption and implementation process:

- Adopting a triggered approach to developing BIM-specific capabilities
- Demonstrating agility in reacting to various opportunities to further the BIM implementation process
- The project setting dictating the use of BIM
- The extent of the organization’s influence within the project supply chain
- The contractual bonds dictating the relationships between project team members
- The lack of BIM requirements from clients dictating the development of the model
- Identified smaller, manageable projects as pilot to develop initial capabilities, on which
4 Assessing and evaluating the impact of BIM

4.1 Assessment and evaluation process

For an organization adopting and implementing BIM, there is a clear need for continuous and consistent assessment and evaluation of the transformational process. First, the organization going through this process must be able to justify the considerable investments required (i.e. measure return on investment (ROI)). Second, the organization must be able to assess the evolution of the transformation. Third, users must be able to receive feedback in order to make any adjustments necessary. Lastly, as is the case in other industries, an organization should be able to compare itself with other organizations in the same field through a transparent evaluation and dissemination process. Unfortunately, the construction industry is notorious for its lack of transparency; therefore such an endeavor represents a considerable shift in mentality for the industry as a whole, which has yet to happen.

The assessment process is characterized by the need for a rigorous data collection method. Clear and consistent metrics must be targeted with a particular understanding of what the analysis of the collected data will yield. The targeted metrics can vary in their degree of subjectivity along a scale whose poles range from perceived impacts defined through qualitative metrics to measured impact defined through quantitative metrics. The depth and breadth of data collection will also vary due to the targeted level of evaluation. At the project level, the breadth of data collection will be more substantial as many data points will be collected at a unique point in time (or over a short period). On the other hand, at the organizational level, data collection will happen over a longer period of time for a chosen number of metrics, hence the depth of data collection will be more substantial while the breadth will be lesser than at the project level (Figure 9). Across this scale, the method in which data is collected will vary from more anecdotal evidence through feedback and perceptions to hard evidence from precise data points collected through various means such as time sheets, project logs and cost reports.

Most organizations have a history of collecting data and assessing certain metrics on a project-by-project basis. Traditional metrics track cost and schedule conformance as well as quality of work performed. However, while these metrics allow overall project performance to be tracked, they do not allow isolating specific factors of project success such as the implementation of a new technology. To address this, more specific metrics have been developed over the years to allow for a more precise measurement of project success and to help in evaluating the impact of new project delivery processes on project outcome. A complete list of metrics is presented in appendix C. However, these metrics are highly project specific, which poses a challenge when evaluating the impact of the transformational process at the organizational level. Isolating the direct impact of the process for the organization itself versus the impact on the entire supply chain is a challenge. Evaluating the evolution of the process requires a constant and consistent measurement protocol.

Depending on the level of precision required and the organization’s history of tracking project data, to assess and evaluate the transition to BIM doesn’t necessarily require additional data to be collected, however it may require that the way in which this data is collected and analyzed be revisited. For example, in terms of actual data collection, Div 15 has a history of tracking cost
components and maintaining a cost database, which is maintained and used by the estimating department. However, while certain cost codes may be deemed sufficient for maintaining the cost database, the level of detail offered by those codes is insufficient to calculate the impact of BIM on a specific project.

In terms of collecting, accessing and visualizing data, the use of centralized project management software, which can create detailed reports of a variety of information pertaining to specific data sets and projects, is highly recommended. Most organizations today have this type of software tool in place, which facilitates the data collection and aggregation process.

In summary, a tentative assessment process is presented as follows:

1. Validate existing data collection techniques, technologies and tools including identifying metrics already assessed.
2. Establish further metrics for evaluation and refine data collection points.
3. Revise data collection techniques and tools to include identified metrics.
4. Collect data at the project level.
5. Build database for long-term data collection at the organizational level.
6. Revisit metrics and data collection techniques and tools as further capabilities are developed.

### 4.2 The impact of BIM

Over the course of this research project, the impact of BIM was evaluated along the scales presented in Figure 9. Through interviews with key individuals as well as analysis of project data, the metrics presented below were developed. At the time of writing this report, projects #1
was completed and project #2 was sufficiently advanced to gather preliminary data. To serve as a baseline comparison for project #1, a district energy project comprising of 4 ETS performed by the organization, where BIM was not implemented was equally analyzed. While the use of BIM is the major differentiator between both projects, another major difference was the added complexity of project #1 due to existing conditions. In addition, as further comparison for project #1, a subsequent phase of the same project, performed in a non-BIM environment by a different contractor served as baseline from a qualitative perspective. The evaluation of the two projects determines the first step in presenting a trend in the impact of BIM, which will be further developed as the organization continues to implement BIM and develop their capabilities.

4.2.1 Perceived impact: the qualitative perspective

The qualitative perspective considers the perceived impact that BIM has had on project outcome and on value created for the owner, the project team as well as the organization. Data was mainly collected through interviews and discussions with different project team members to get feedback on their experience in each project setting. Overall trends become apparent when discussing the different projects, which can lead to a generalizable sense of perceived value creation or loss. Furthermore, anecdotal evidence, based on an individual’s experience in the field, is equally valuable in evaluating the impact of the transformational process.

The perceived impact at the organizational level was:

- **Increased visualization, coordination and validation capabilities**
  Consistent with findings from other research endeavours, the modeling process offered the possibility to visualize, coordinate and validate the design prior to construction. These three capabilities, offered by the modeling process, are at the heart of many, if not most, of the benefits attributed to BIM. When interviewed for project #1, the construction manager stated that the modeling costs were entirely justified seeing as they had “a lot to lose” on this project due to its complexity. The interviewee mentioned the capacity to resolve conflicts prior to fabricating elements as a major time saver and pointed towards the overall quality and reliability of the documentation that was being produced and sent to site as a major benefit of the use of BIM in this project. In project #2, the modeling effort resulted in added value to the client through the resolution of costly issues prior to construction.

- **Increased opportunity to offer additional services and added value to clients**
  The transition to BIM offered the organization the opportunity to develop parallel skill sets which offers the possibility to influence both project outcome and the organization’s bottom line. For project #1, the organization developed the capability to perform laser scanning and are now increasing this capability on subsequent projects. Laser scanning represents a new service which is now being offered by the organization and therefore is contributing to it’s revenue stream. It is too early to quantify this impact, however to date it is seen as being positive. In project #2, the modeling effort resulted in added value to the client through the resolution of costly issues prior to construction.

- **Increase in requests for proposals and invitation to bid on larger projects**
  The organization noted a spike in the number of invitation to participate in larger projects where the use of BIM was targeted due to the organization’s leadership in the field and their relational attitude towards project delivery.
• **Increased leadership within the supply chain**
  On project #2, the organization gained credibility and prominence within the project team through the modeling process. By bringing a coordinated model to the table Div. 15 took ownership of the project, the firm has thus offered increased value to the client as well as to the general contractor by mitigating costly issues upstream.

The perceived impact at the project level was:

• **Increase in overall client satisfaction**
  When comparing project #1 to a subsequent phase of the same project performed by an other mechanical contractor where BIM was not used, the client for this project noted a significant difference between the quality of the installations between both projects. Having the capacity to visualize and validate the installation of the equipment for maintenance purposes, the client stated that there were less “unpleasant surprises” when the project was delivered through BIM. In addition, although fewer ETS were delivered in the subsequent phase (4 ETS vs. 8 ETS in project #1), the project was delivered 6 months late compared to 2 months late for project #1. The client is now looking towards implementing BIM on the remainder of the phases for the district energy project while increasing the requirements for off-site pre-fabrication to minimize disturbances on-site.

• **Better conformance to original project scope and intent**
  As mentioned, the client did perceive a big difference between project #1 and the subsequent phase in term of conformance to original scope and intent. In project #1, through the use of BIM, the client was able to validate the location of valves and other elements for serviceability purposes. Where BIM was not used, there was more variability between the original intent and actual execution.

• **Increase in the quality of communication and information flow**
  For project #1, the client noted an increased in the quality of as-built drawings obtained compared to other similar projects. Furthermore, according to the construction manager, there was a significant improvement in the quality of information going to site. In project #2, the drawings that were produced from the model were used to communicate intent with installation and sequencing of work. This was seen as greatly beneficial to the entire mechanical supply chain.

• **Ease of project execution and interaction with the supplier**
  The client noted no significant difference in his interactions with the supplier that was attributable to the use of BIM.

• **Perceived quality of work**
  For project #1, there was no perceived difference in the quality of workmanship between the two phases of the institutional district energy discussed with the client for project #1. Also, the organization attributes the high quality of as-built drawings to the use of BIM.
4.2.2 Measured impact: the quantitative perspective

The quantitative perspective considers the measured impact BIM has had on project outcome and on value created for the owner, the project team as well as the organization. Data on project #1 was mainly collected through project logs, timesheets, estimates and other hard project data captured through the project management software and project documentation.

The measured impact at the project level was:

- **Increase in personnel productivity**
  The impact of BIM on personnel productivity was positive. There was a 2.2% reduction in site supervision costs and a 1.0% reduction in project management costs between project #1 (BIM project) and the baseline DE project (non-BIM project) (based on total project cost).

- **Increase in budget conformance**
  The impact of BIM on budget conformance was very positive. There was a 23% reduction in cost variance (estimated cost vs. actual cost) between project #1 (BIM project) and the baseline DE project (non-BIM project).

- **Increase in information accuracy**
  The impact of BIM on information accuracy was very positive. During an interview with the project manager for project #1, it was stated that, from experience, the issued for construction drawings (IFC) were typically complete and accurate to 25%. He estimated that the modeling process rendered those drawings up to 85% accurate and complete. The remaining 15% was being figured out in the field. Therefore that gap in accuracy and completeness translates itself to time spent in the field. By reducing the amount of resolution in the field, the organization was reducing time thus increasing productivity.

- **Increase in prefabrication efficiency**
  The impact of BIM on pre-fabrication efficiency was positive. In both cases, most elements were pre-fabricated on-site prior to installation. The main difference was the way in which the information was conveyed to the fabricators. This information was seen as being much more reliable and precise leading to a better and more efficient pre-fabrication process. Elements were deemed to be prefabricated faster and on a larger scale.

- **Amount of deficiencies and rework**
  No evidence was found for the impact of BIM on amount of rework and deficiencies. Cost of rework and deficiencies was negligible in both cases, 0.01% for the baseline project and 0.07% for project #1. The actual data collection may be in cause as a specific cost code was put in place for deficiencies, however the extent to which the employees utilized this code and their understanding of what comprised a deficiency or re-work should be further investigated. That being said, while hard data is difficult to come by regarding this metric, feedback from site personnel speak to substantial decrease in potential rework due to the quality and the reliability of the information that was being transmitted to site.
• Number of RFIs, COs and CDs
  No evidence was found for the impact of BIM on the quantity of requests for information (RFI), change orders (CO) and change directives (CD). These metrics are widely popular for the measurement of the impact of BIM on project outcome. Many projects have seen a significant decrease in RFIs, COs and CDs when BIM was implemented in a collaborative setting from the onset of the project. In this case, no significant reduction in RFIs, CO or CDs was observed in the projects analyzed. This could be due to the “lonely” setting in which BIM was deployed, the stage at which it was deployed as well as the overall complexity of the project.

• Site Safety
  No evidence was found for the impact of BIM on site safety. In the projects analyzed, no incidents were reported which impacted project delivery, therefore the impact of BIM on site safety could not be assessed.

From the organizational perspective, keeping track of the impact over time will dictate the effectiveness of the transformational process and allow the organization to either adjust or target certain areas of improvement. Across the entire scale, increasing the depth of data collection will allow the organization to outline trends and correct them if need be.

4.3 Organizational Assessment Matrix

The Organizational Assessment Matrix (OAM), developed by the CICRG, is a tool that allows an organization to plan and evaluate their internal BIM adoption and implementation process. Mainly developed for owners, some tweaking is necessary to fit the realities of the specialty contractor prior to conducting the assessment exercise. However, overall, the OAM does help in targeting specific areas of improvement.

In this case, the assessment exercise utilizing the OAM was conducted with the organization’s BIM committee to evaluate and target areas of strengths and weaknesses in the BIM adoption and implementation process (Figure 10). The main outcomes of this exercise were that while the organization had a very clear strategic approach to BIM adoption and implementation, they were lacking in the process and information categories. More specifically, they lacked in their documentation of external project and internal organizational BIM processes as well as in the definition of their Model Element Breakdown Structure and the Level of Development to which the model elements are completed.
Figure 10 - Organizational Assessment Matrix (CICRG, 2012)
5 Discussion

This section discusses the main challenges and lessons learned of the BIM adoption and implementation process within a specialty contractor working in the mechanical field.

5.1 Challenges

The main challenges encountered were:

- **The contextual/environmental factor**
  Over the course of the research project, the business context was seen to largely influence the rate of BIM implementation within the firm. The procurement method also heavily influenced the choice to deploy BIM. To date, the firm has only been capable of deploying BIM in a mostly ‘lonely’ setting where all modeling work was performed in-house, limiting the potential impact of BIM on project outcome. While the firm is actively seeking projects which will deploy a more collaborative BIM setting, there seems to be an overall lack of such projects being commissioned either because clients and owners are going the more traditional route or because of legal and procurement barriers that hinder the flow of information across the supply chain (i.e. projects being designed in BIM but being tendered in 2D, paper-based sets). Therefore, the possibility of furthering the BIM implementation process is being limited by the actual opportunity to implement BIM, which leads to a “triggered” implementation process.

- **Inconsistency in the deployment of BIM at the project level which influences the extent of the use of BIM**
  Varying levels of “buy-in” towards BIM across the supply chain are seen to heavily influence the extent to which BIM is being deployed within a project setting. However, due to the mechanical contractor’s considerable scope of work, he is seen as still benefiting from implementing BIM on his own, though not as much as if the entire project supply chain is developing the BIM. In a lonely setting, the effort expended on the modeling process will be much more onerous and thus diminish the potential ROI.

- **Lack of control and influence on the project delivery method**
  The type of contractual relationships forged in the project supply chain are seen as influencing how the coordination efforts are being received by other members of the project team. As illustrated by project #2, the lack of contractual relationship between the mechanical and electrical contractor lead to conflicts even though the mechanical contractor had modeled and coordinated all elements that were to be installed in the ceiling space. By acting on his own and disregarding the coordination effort put forth by Div. 15, the electrical contractor rendered the modeling and coordination effort partly irrelevant.

- **Hiring and maintaining personnel with adequate modeling and coordination capacity**
  A general lack of qualified and capable personnel has an impact on the extent to which BIM is being used at both the organizational level and the project supply chain level.
There is also the risk of keeping the personnel once they have been trained by the organization. One way to mitigate this risk is by including clauses in the contracts through which employees must stay a minimum amount of time after their training or reimburse the cost of the training should they choose to move to another company.

- **Choosing the appropriate software suite and managing technology**
  Technology management can be seen from two perspectives. First the implementation of BIM requires substantial investments in terms of hardware and software to run the models, communicate the information and share data. Many specialty contractors have limited capabilities, which aren’t sufficient to run today’s complex models. In addition, maintaining these capabilities becomes an added cost, which must be factored in to an organizations expenses. Furthermore, there is a general reluctance to pass on this cost to the client by increasing bids on projects, as this increase may well cost the organization the project due to the lowest bidder mentality so prevalent within the Canadian AEC industry. Second, developing additional capabilities and expanding the scope of technology use requires a solid implementation and deployment plan with specific and localized resource allocation. In both cases, the adoption and implementation of BIM must be seen as a long-term investment with varying return on investment (ROI).

- **Garnering an adequate understanding of the transformational process**
  One of the main organizational challenges in implementing BIM within Div 15 has been garnering an adequate understanding of BIM and how it affects the employees and their workflows. Due to this lack of understanding, the firm has had to “feel their way alot”, implementing BIM by “trial and error” which led to some frustration on the part of management as well as the employees. Timelines and schedules, deliverables and workflows were being disrupted by the introduction of BIM and the firm is slowly adjusting as they gain more and more experience.

- **Evaluating ROI**
  Evaluating ROI is a result of the impact assessment and evaluation process. The same considerations apply to the ROI calculation in that return ranges from perceived to measured and from project level to organizational level. Therefore, while the organization is the one investing, naturally the return is felt on a project basis. Thus, evaluating ROI at the organizational level is initiated at the project level. To date, ROI for Div. 15 has been perceived in a much more compelling way than it has been actually measured. In both projects #1 and #2, the organization benefitted from significant extra cost avoidance due to the visualization and validation capabilities as well as the increased information accuracy. In project #1, as discussed, due to the existing conditions, the labour costs could have been much more significant had Div. 15 not used BIM. This represented a direct saving to the organization. In project #2, the return was more widespread as the impact of the modeling process benefitted the whole project team.

As an initial effort to quantify ROI of BIM in case of project #1, it is possible to look into the hard data that is available. While BIM costs amounted to 4,1% of total project costs, the reduction in supervision and management costs amounted to 3,2% of total project costs. By compounding this quantitative effect to the less quantifiable benefits mentioned before, it is possible to see that the costs associated with the modeling process were most
probably recuperated, if not more, hence denoting a positive ROI for project #1.

At the organizational level, by continuously tracking the ROI on specific projects, Div. 15 will be able to dictate the trend in ROI attributable to the use of BIM. This is an on-going process and will require a rigorous and iterative data collection process across multiple projects.

5.2 Lessons learned

The main lessons learned were:

- **The importance of a consistent and coherent organizational strategy in the BIM adoption and implementation process.**
  Developing and communicating a clear, consistent and coherent organizational strategy towards BIM was seen as being a determinant factor in the success of Div. 15’s on-going implementation effort. By setting clear, attainable and measurable goals the organization ensured that a path forward was drawn and could be held to throughout the organization.

- **Isolating the BIM adoption and implementation process**
  As the transition to BIM for a mechanical contractor represents a complete departure from the traditional workflows, there is an opportunity to somewhat isolate the process and focus it on a specific project by project basis and control the implementation process while reaping immediate benefits. While deploying BIM in a completely collaborative setting, the specialty contractor’s position in the supply chain and the control over his personal scope of work allow the specialty contractor to see immediate benefits to the BIM adoption and implementation process, through direct control and influence over his own workflows.

- **The necessity to strike a balance between a top-down and bottom-up adoption approach and the creation of a steering committee with sufficient decisional power**
  While the vision and strategy for BIM came from top management, it was the user-base that ultimately made the decisions that would impact their day to day functioning such as the software choice. In addition, the tribune offered by the BIM committee for management and user base to meet and exchange on issues and developments was crucial to a clear communication of expectations, intent and execution within the organization. Furthermore, empowering the user base through decision making and possibility to explore and expand capabilities ensured a buy-in which is equally critical in the adoption and implementation process.

- **The importance of an agile approach to the transformational process**
  While, as previously mentioned, overall context will modulate the rate of diffusion within the organization, specific project environments will modulate the depth and the breadth of its deployment, thus influencing the organization’s preparedness to deploy BIM. This preparedness will be influenced by the personnel that is available at the required time, their level of expertise and their capacity to execute the project requirements. Therefore the organization must demonstrate incredible agility to navigate and choose which projects to get involved in and to what extent, least they become overwhelmed and cannot meet demand. To date, the firm has not been faced with this challenge due to a restrained
demand for BIM, however, in the near future, and with the firm’s growing expertise and reputation, this question of preparedness and agility will become an issue.

- **Suitability of BIM within the organization: Is BIM right for the organization?**
  Before any implementation effort was put forth, the decision makers within the organization evaluated the suitability of BIM from their business perspective. For certain specialty contractors, transitioning towards BIM and other technologies makes sense, for others however, the return may not be worth the investment. Typically, specialty contractors whose work involves much coordination with other trades will benefit from being able to resolve issues in the office rather than in the field. That being said, as BIM gains in popularity and collaborative environments evolve to suit this transition through modified procurement and project delivery processes, specialty contractors will be called upon to play an increasingly important role in the modeling process.

- **Lack of field personnel in the BIM steering committee**
  One thing that was observed is that no field personnel was involved in the firm’s BIM committee (aside from the Construction Manager). Therefore, there was little feedback from the field personnel at the moment of making decisions that would impact the information flow. Moving forward, as the firm integrates other technologies, it would be worthwhile to get some key personnel from the field involved in the evaluation process to gain their insight and feedback on the implementation process as well as further define the information and workflows at the office-field interface.

- **Establishing clear uses and requirements for the model**
  In the transition to a BIM environment at the project level, the establishment of uses and requirements for BIM is one of the most crucial steps in ensuring the success of the entire BIM effort. A struggle is apparent between the expectations for the model, the intent with the modeling process and the execution of the modeling process itself. As BIM is relatively new, contractual requirements for BIM are often vague and not well defined. Furthermore, the intended uses of the BIM may be conflicting between the design, construction and operations phase. Thus three avenues of consideration become apparent in the implementation of BIM in a project setting: first, respecting the contractual requirements for BIM, second, ensuring that the scope of work included in the BIM allow the collaborating project team members to perform their work and third, ensuring that the organizational scope requirements (ie. what the BIM will be used for in the scope of work performed by the organization itself) be met. In parallel, a clear alignment must be achieved between the expectations for the model, the intent of all project team members in the modeling process and the actual execution of the model.

- **Challenges associated the impact assessment and evaluation process**
  Many challenges were met in assessing and measuring the impact of the transformational process. First and foremost, isolating the impact of BIM is almost impossible due to the quantity of factors that will impact any given process within the construction sector. Second, lack of precision in data capture at the source (ie. time sheets and units performed) will skew the results of the assessment exercise and ultimately render the results unusable. Lastly, defining and tracking the right metrics throughout a project is a challenge due to ever evolving realities of the project environment.
Moving forward, some recommendations can be formulated from this experience. First, like any implementation effort, there must be support from the top management and buy-in from the users. The goals and objective of this performance measurement must be communicated to all the employees in order to ensure their buy-in since the collection of data will start with them. Secondly, when reviewing the data from past projects it becomes apparent that data which is crucial to assessment is not being captured. Issues like cost codes which encompass too many activities or elements, time sheets with too little information, skewed budgets, etc. have to be addressed by modifying what is captured and how it is captured. Thirdly, some productivity measures were simply lacking due to not being captured. Measures such as units performed during a shift were missing from time sheets. Lastly, as illustrated by the projects studied, many benefits of BIM implementation are not easily quantifiable. There is the possibility of estimating the costs associated to issues that were caught through the model, however this evidence remains more anecdotal.

6 Conclusion

This report has presented the BIM adoption and implementation process from a specialty contractor working in the mechanical contracting field. This process was presented from two perspectives: the organizational perspective presenting the process behind the BIM adoption and implementation effort at the organizational level and the impact this has on the organizations internal structures and workflows and the project perspective presenting the process behind the BIM effort at the project supply chain level and the impact this has on external structures and workflows.

The main objectives of this research were: (1) To document the BIM adoption and implementation process for a specialty contractor in the AEC industry from an organizational and project supply chain perspective; (2) To evaluate the impact of this transformational process within the organization and across it's project network; and (3) To determine avenues of development for productivity gains using BIM and other IT tools.

An approach to assessment and evaluation of the impact of BIM implementation on project outcome was discussed. While the findings presented did indicate an overall positive impact on project performance at a high-level, further work is required to validate these findings. By implementing a robust approach to performance measurement, the organization will, in time, be able to further justify the initial and continued investments required in their transition to BIM.

Benefits, challenges and observations on the BIM adoption and implementation were presented and discussed following the assessment exercise. Many of these benefits and challenges reflect the findings of other research endeavours. However, this research project was unique in that it looked at both the organizational and project levels and discussed the BIM adoption and implementation process from these concurrent perspectives.

As previously mentioned, further work is needed to collect more data concerning the assessment and evaluation of BIM on project outcome. In addition, due to the research project’s relatively short time frame, one of the initial objectives concerning the study of pre-fabrication could not be fully carried out. Therefore, further work in this sector is needed to verify the impact of BIM on pre-fabrication and their combined impact on project outcome.
7 Acknowledgments

This research study was funded by the National Research Counsel – Industrial Research Program (NRC-IRAP) and the Centre d’études et de recherches pour l’avancement de la construction au Québec (Center for Study and Research for the Advancement of Construction in Quebec) (CERACQ).

8 References

Appendix 1: Research setting

1 Objectives

The Division 15 Mechanical ltd. pilot project aimed to study the adoption and implementation of building information modeling tools (BIM) and their associated processes as well as to evaluate and develop avenues for potential productivity gains through workflow improvement and pre-fabrication within a small or medium enterprise (SME) working in the Mechanical contracting field. The pilot project focused on three determinant axes of BIM deployment within a SME:

- Driving BIM adoption throughout the organization;
- Driving BIM implementation at the project team level from the organizational perspective;
- Assessing performance.

More specifically, the project aimed to study the BIM adoption and implementation process from both the organizational and project supply chain perspective. The objectives of the research were the following:

- Evaluate the impact of BIM implementation within a specialty contractor in the AEC industry;
  - Impact on workflow productivity;
  - Impact on value;
- Evaluate the impact of BIM implementation across a mechanical sub-supply chain;
  - Impact on workflow productivity;
  - Impact on value;
- Map out the industrial processes that lead up-to effective use of BIM tools for the pre-fabrication of elements for field use.

Over the course of the research project, due to time constraints, the objectives were realigned to focus more on the BIM adoption and implementation process and its impact at both the organizational level and the project level. It is important to note that while the objectives speak of studying prefabrication and its synergy with BIM tools (namely objective 3), the timeline dictated by the research project did not allow for sufficient data collection opportunities. Thus, the objectives of the research were realigned to focus more on the actual modeling and impact these models have on-site.

These re-aligned research objectives were to:

- Document the BIM adoption and implementation process for a specialty contractor in the AEC industry from an organizational and project supply chain perspective;
- Evaluate the impact of this transformational process within the organization and across the organization’s project network;
- Determine avenues of development for productivity gains using BIM and other IT tools.
2 Research project execution

The research project was carried-out over a 10 month period during which a 4 staged, mixed-method approach was deployed. The 4 stages were: (1) Benchmarking the current state of the organization, (2) Defining the desired state and metrics to evaluate the BIM implementation process and its impact, (3) Deployment and documenting of the BIM implementation process, and (4) Data analysis and feedback.

Data was collected through semi-structured interviews, in-situ observations, participation in project meetings and intra-firm meetings and through informal discussions. This data was used to benchmark the organization and gain an understanding of the employees involved in the BIM implementation process current work practices, map out processes and information flows and provide a means to evaluate the performance measures. Interviews took place over the period of a week where top management personnel as well as project managers and the BIM manager were interviewed. They lasted between 1h00 and 1h30 and were directed at gaining insight into the functioning of the firm, the BIM adoption process and how the firm was going about with the transition towards BIM. Quantitative data such as cost data, time sheets, BIM models, plans and other project specific documents were supplied by the firm.

During stage 1: benchmarking, the “Organizational Assessment Matrix”, prepared by the Computer Integrated Construction Research Group (CICRG) at Penn State University, was used as a means to evaluate the current state as well as the desired state of BIM adoption within the organization. This assessment was performed during a meeting with the BIM committee and the results were consensus based. The results are presented below. The main limitation of this process was that the original intent of the matrix is geared towards the owner’s perspective and thus, certain categories are questionable in their relevance to the specialty contractor’s perspective.

In attempting to establish return on investment (ROI) and measuring the impact of BIM on productivity, two comparative projects were analyzed. Both projects were developed in the same project stream (explained below). One was executed without BIM and the other was executed with BIM. The analysis is presented subsequently. For this analysis, cost data, estimates, time sheets, drawings and models were analyzed. Interviews were also conducted with the management personnel involved in both projects to discuss personal experience and perceptions about the BIM implementation process at the project level.

In terms of limitations to the research project, access to members of the project teams residing outside the organization was the biggest limitation to achieving a comprehensive understanding of the impact of BIM at the project network level. This was mainly due to two reasons: first, constraints and external pressures on some of the projects dictated that there was little or no time for conducting research and two, the role of the organization within these projects dictated the use of BIM and thus the extent to which BIM was deployed throughout the project team. Hence, the perspective presented in this report is that of the mechanical contractor alone. Furthermore, while tremendous access to project data was granted by the organization, the way in which the data is collected and compiled by the organization, while sufficient to fulfill the requirements for
their accounting, lacked some detail for research needs. This points towards the need for more robust data collection at the organizational level in order to facilitate the quantitative benchmarking process. Lastly, the time frame in which the research project was carried out should be extended in order to allow for a more longitudinal data collection period.
Appendix 2: Project delivery process

1 Traditional project delivery process

Div. 15 typically delivers projects through two different procurement methods: Traditional Design-Bid-Build (DBB) and Design-Assist (DA) in a Design-Build (DB) or Construction Management setting. Traditional project lifecycle phases, as developed by the AIA are, Pre-Design, Schematic Design, Design Development, Construction Documents, Tender/Permitting, Construction, Closeout and finally Operations.

1.1 Design-Bid-Build (DBB)

By far the most popular procurement method in Canada, the DBB procurement method is one that is found when working on large institutional, governmental or large commercial projects, among others, where owners wish to receive the lowest initial price for the delivery of a project based on tender documents produced by a team of consultants. Div. 15 will typically pick and choose projects that they wish to participate on instead of bidding on every project that is out to tender. Interviewee #1 and #2 have noted that this procurement method is not desirable due to the laborious process that is the tender phase. In fact, over the years, they have marked a notable decline in the quality of the design and the drawings, which lead to an increase in Requests For Information (RFI) during tender phase. They impart responsibility to shortened deadlines imposed by clients. Thus, the tender process is wrought with uncertainties and the evaluation of project cost is largely based on the experience and knowledge of the personnel who are involved in the estimation process. In a DBB contract, the mechanical contractor has no design responsibilities. Fig. 2 illustrated the DBB phases and stakeholder involvement for the mechanical contractor.

1.1.1 Estimating within the Tender phase

Tender is usually the first step in obtaining a contract under the DBB procurement method. Estimations are based on a set of 2D drawings and specifications provided by a team of consultants, at varying levels of detail. In the case of a DBB contract, documents are generally taken to be complete at 100%, though from the interviewee’s experience, this is rarely the case. Typically, the estimators will work with the General Manager and the Construction Manager to process the documents and outline the project scope on which to bid. In addition, on certain projects, they might involve key personnel (Project Managers, Foremen, etc.) to impart additional knowledge and refine the bid. The “estimating team” will generally go over the project documents and attempt to quantify each element and attach a cost to it’s procurement, installation, commissioning and servicing/warranty. Attributing a cost to elements is based on quantity with several factors linked to each particular element such as difficulty, schedule, labor, and several other extraneous factors such as weather and market conditions which are compounded into the final estimate. Furthermore, it was
stated during one interview that additional provisions were made based on the consulting firms that worked on the design due to previous experience with working with these consultants. In essence, outside of the actual count and measure of elements as represented on the plans, there is a considerable amount of factors which are taken into account that rely on the experience of the estimating team. During the tender process, the estimating team and the subcontractors who are pricing out the work will submit RFIs to refine the design intent and get as much information as possible. Clarifications of plans will be produced under the form of addendum by the design consultants. It is at the tender phase that equivalency requests are usually submitted. Estimating in this context is a highly punctual and rigid process with a distinct input (tender documents + RFIs) and a distinct output (bid).

1.1.2 Contract Award, Project Startup and Mobilization
In the case of a DBB project, success will generally mean that the company has submitted the lowest bid. Once confirmation is given and the contract is awarded, the team that prepared and submitted the bid will generally review the entire package, involving the Project Manager more closely this time, to comb over the project once more, go into greater detail and ensure that no major elements were overlooked or errors committed during the tender phase that could impact the project delivery. The General Managers involvement with the project team will ebb as the Project Manager gets more and more involved and takes control of the project. At this time, equipment with long lead times will be ordered and a preliminary schedule will be determined. In parallel, it is at this time that the project team will be assembled, including project coordinator and field staff. Contracts will be awarded to sub-contractors based on negotiations involving all those that have produced a bid. One interviewee said that it was at this point, during negotiations with sub-contractors, that any errors or omissions that were made during tender would be negotiated and “patched-over”, risk being essentially transferred to the sub-contractors as much as possible. Shop drawings will be submitted by sub-contractors through the GC, reviewed by the consultants and redistributed so that equipment and materials can be ordered and fabrication can begin.

1.2 Design-Assist (DA)
Div. 15 prefers the Design-Assist project delivery method for many reasons. First and foremost, it allows Div. 15 to deploy its expertise and “create an overall better project”. It also allows the company the opportunity to develop relationships and create value. Typically, DA will be deployed in a Design-Build or Construction Management procurement context, with the mechanical contractor working for a GC in a Construction Management role. The interviewees state that while there is more work that goes into getting a DA contract, there usually is less competition. Typically, DA projects will be on an invitation basis where the company will compete against other firms to obtain the contract. There will be a first round of qualitative assessment of the project team put forth by the competing firms, in the form of a Request For Quotation (RFQ),
which narrows the field from 5-6 firms down to 2-3. The RFQ will contain the description of the firm’s experience as well as the description of the project team and their individual experiences. It will also contain a high level quote for work, which is based on very high-level preliminary plans. The project team will then refine the project documents while continually validating the price with the remaining contractors. Once design is considered sufficiently advanced to set a firm price, the 2-3 remaining firms will produce a bid, in the form of a Guaranteed Maximum Price (GMP), for the completion of works relating to the design and construction of their particular scope of work. Fig. 3 illustrates the DA phases and stakeholder involvement for the mechanical contractor.

1.2.1 Design
The DA delivery method requires close collaboration between the consultants and the mechanical contractor. In this context, there is an open dialogue between team members and the consultants are open to suggestions from the field in regards to alternatives or equivalencies. This allows for opportunities to create value at an earlier stage in the project by integrating the individuals who will actually be performing work.

1.2.2 Estimating
Under the DA procurement method, estimation also accounts for a major portion of obtaining a contract, as the contractor must submit a GMP. The estimation process is an iterative one. As design is being refined, so is the estimate becoming more and more precise. This allows for a tighter control over the budget as well as presents opportunities to optimize certain design decisions. These design decisions can be rapidly priced via the estimating team and informed decisions can be made as to how to proceed. Estimating in this context is an evolving and iterative process with many inputs and many outputs.

1.2.3 Project Startup and Mobilization
Similarly to the DBB procurement mode, mobilization happens once contracts are awarded and the project has sufficiently been detailed in order to obtain permits and begin construction. However, as the project team has been working together for a longer period of time and that all stakeholders essentially have a good overall grasp of the project, the project start-up phase tends to be much smoother than in the DBB mode. Equipment having long lead times can essentially be ordered during the design phase, once they are determined. Also, many issues have been resolved during design due to a closer integration of the project team. However, as this process still is happening in a 2D, paper-based environment, issues still tend to arise during construction, which could not have been worked out, from the onset. The resolution cycle in a DA is more cooperative though, while still being submitted through the RFI process, due to the nature of the contract.
Improving Efficiency And Productivity In The Construction Sector Through The Use Of Information Technologies

Fig. 2-1 – Traditional Construction Workflow

Pilot Project II: Division 15 Mechanical Ltd.
March 2013
1.3 Construction
Once project teams are mobilized and the construction phase is under way, the project will evolve according to the schedule set forth and agreed upon with the GC and coordinated with the other sub-trades. Under both procurement modes, the construction phase is similar in that it is comprised of a series of activities and tasks, linked together, to create what was laid out in the design phase and set out in the plans and specifications. The project manager, project coordinator and foreman are in constant communication, communicating daily via e-mail and telephone. The site foreman will be in-charge of day-to-day activities, ensuring that the right materials and equipment are on site for the journeymen to accomplish their work. The project manager will be looking ahead to anticipate the schedule and ensure that the project runs smoothly. Acting as a liaison between the mechanical contractor and other consultants and contractors, the project coordinator will prepare and communicate all relevant documents (RFIs, POs, etc.). Fig. 2-1 illustrates the traditional on-site workflow during the construction phase.

1.4 Requests for information
The construction phase is relatively linear. When issues arise, a disruption in the construction sequence is created. In order to deal with these issues, the project team will proceed using the RFI process. Workers who are performing the work will typically raise any issues in the field. The issue will be identified to the site foreman who will relate it to the project manager either through verbal communication (via telephone) or pictures and words (via e-mail). The project manager will assess the situation with the foreman to evaluate the gravity of the issue. If the solution is easily found and does not have any impact on the design and/or performance of the system being installed, the issue will be solved then and there and work will continue. This resolution loop is fairly straightforward and

Fig. 2-2 – RFI process
does not have a major impact on cost and schedule. However, if the issue impacts design and system performance, a formal RFI will be submitted to the consultants for clarification. The project coordinator will create the RFI with input from the PM and the foreman and relay it to the GC who will then transfer it to the appropriate consultant. The consultant will propose a solution, which is sent back to the project team via a Site Instruction (SI) if the changes are deemed to not impact cost or a Contract Change Notice (CCN) if the resolution is deemed to impact cost and/or schedule. Under an SI, the work is completed with little or no impact to the overall project performance. Under a CCN, depending on the nature of the issue, the consulting team can issue a Change Order (CO) or a Change Directive (CD). The change directive is executory and entails that the contractor perform the work immediately and submit a price for additional work. The change order entails a back and forth negotiation where a solution is priced out and re-submitted until a satisfactory solution is agreed upon by all parties. Understandably, this process takes time and is not well suited to the sequential, highly dependent nature of construction tasks. An interviewee stated that an RFI process can take anywhere from 3 days to 3 months to resolve. During this resolution time, work is halted on the problem area and workers must be reassigned to other areas within the project. In both cases (CO or CD) there is a negative financial impact on the project and project performance is lessened. Fig. 2-2 illustrates the typical RFI process.

1.5 Closeout
At project closeout, the mechanical contractor must make sure that all installations are functioning properly. Thus, the commissioning period is an important aspect of his work. Deficiencies will be noted by the consultants, which have to be rectified by the contractor. All occupancy documentation, such as project manuals, must be compiled and handed over to the owner’s operations teams. In addition, as-built drawings are produced and included in the closeout documentation. Typically, final payment is conditional to the reception of all specified documentation.

1.6 Post-Mortem
Typically, the project team is disassembled sequentially as the project moves forward, the constants being the PM, the PC, the foreman and the site superintendent. Once the project is completed, members of the project team will move on to a different project, sometimes overlapping two projects consecutively depending on size and nature of the concurring projects. This means that there is usually little time to do a project ‘post-mortem’ and evaluate how the project went and formalize any lessons learned to be communicated to the rest of the company. During an interview one of the interviewees stated that a post-mortem was only done when the project went wrong. However, cost data is one element that is constantly being evaluated and kept up-to-date to be reused in subsequent bids. Div. 15 is also working on a weld-length performance measure where they will be determining performance of welders on what lengths of weld are being produced on a hourly basis.
1.7 Intra-organizational Communications
Div. 15 will hold internal project review meetings with all project managers on a monthly basis to go over the various projects, their advancement and any issues or opportunities that have arisen during execution. Similarly, the foremen hold a monthly meeting with the construction manager to go over the various projects.

2 BIM-based delivery process
Div. 15 have developed workflows in an ad-hoc manner to accommodate BIM deployment within a project team. This is explained by their “trial and error” implementation and deployment process. Currently, all BIM projects are modeled by the BIM coordinator, which acts as a supporting actor to the main project team.

2.1 Tender/estimating
Div. 15 have yet to deploy BIM at the tender stage to quantify and price jobs, as they usually have too little time and the inherent risk of developing the model and not getting the contract is too great. The bidders also do not typically have access to CAD plans and creating a model from 2D paper-based plans (.PDF) would be too onerous of a task considering the marginal benefits that the process would grant. However, every new project that is being bid on is being considered in respect to its “potential for BIM”. As previously stated, no allocation for modeling is being included in the bid as Div. 15 have yet to quantify BIM to allow for this. In a design-build/design-assist mode, Div. 15 does possess a little more leeway in terms of building the BIM. As of yet, no cost data is included in the BIM as its level of detail is incomplete and only portions of the buildings are being modeled. This will change as projects integrate BIM more and more and complete BIMs are created by all project team members. However, Div. 15 has no plans of transferring cost data into the BIM.

2.2 Project start-up
At project startup, the BIM coordinator will discuss with the general manager, project manager and the field personnel as well as refer to the plans and specifications in order to gain an overall understanding of the project scope. In parallel, she will gather information and any models from consultants. If models are unavailable, she will work with the 2D drawings to create the model, while focusing on certain areas of interest, targeted at the onset of the project, such as mechanical rooms or heavily congested spaces (shafts and ceiling spaces).

2.3 Modeling and project coordination
During the modeling process, the BIM coordinator will be in constant contact with the project manager and the site foreman in order to create an accurate model that will be transferable to the site. As 2D drawings are currently being translated to 3D models, the assembly process and spatial interactions are being worked out. Thus, it was stated by interviewee #4 that while 2D drawings were maybe
25%-30% accurate and complete, translation to a 3D model by the BIM coordinator rendered them to an accuracy of 85%. The final 15% was achieved within the model through iterative design and discussion with the foreman and the project manager (Resolution loop).

Coordination with the sub-trades is achieved at the modeling stage. However, Div. 15 has little experience with full model coordination as they have not yet had the opportunity to work in a fully 3D environment. As stated, project #1 involved work that fell solely within the mechanical contractors scope (plumbing and equipment installation). Thus coordination was limited with other sub-trades. However, as the team had, through laser scanning and site surveys modeled 8 of the mechanical rooms that were to be receiving this new distribution, several issues and conflicts with the existing were found and coordinated prior to construction and site installation. In the case of project #2, Div 15 has modeled every element that was to be installed in the ceiling spaces including cable trays, piping, ductwork and fireprotection. Thus, the modeling effort deployed went beyond the scope of Div. 15’s work, however, it paid off as severe issues with ceiling space were found and corrected prior to construction.

2.4 Construction
Output from the model for construction purposes is paper-based. The BIM Coordinator produces sheets, which show plans, elevations and isometric drawings of assemblies to be built. These are sent via e-mail to site where the foreman receives them, prints them out, marks them up and distributes them to the journeymen and weld teams. Interviewee #2 stated that the drawings produced from the 3D model where much more detailed than sets of drawings that would traditionally be found on site. These isometric drawings gave the workers a clear direction to go thus reducing uncertainty in the field. In other words, what was to be built was clearly identified and the thought process behind fabrication and assembly was streamlined for the worker. In case of conflicts raised in the field, the RFI process is initiated with the exception that the relevant portion of the model will be included in the RFI.

2.5 Project close-out
At project closeout, additional documentation provided by Div. 15 relating to the BIM model will be isometric weld-maps and as-built drawings. This information is graphically entered on the drawings and is not part of the BIM model. Fig. 2-3 illustrates the workflow on a typical BIM mechanical contracting project.
Fig. 2-3 – BIM Construction Workflow
### Appendix 3: Proposed performance metrics

#### Table 1: Proposed performance metrics from the literature

<table>
<thead>
<tr>
<th>Metric</th>
<th>Measurement</th>
<th>Source</th>
</tr>
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| Actual cost vs. Estimated cost | • Estimate for cost of labour ($)  
                          • Actual cost of labour ($)  
                          • Estimate for cost of material ($)  
                          • Actual cost of material ($)  
                          • Detailed Cost conformance (%) | • Garrett and Garside (2003)  
                          • Khanzode (2010)  
                          • Kunz and Fischer (2012)  
                          • Suermann (2009) |
| Cost of modeling vs. Cost of work | • Cost of 3D modeling ($)  
                          • Cost of overhead ($)  
                          • Actual cost of work ($)  
                          • Man hours spent per project - efficiency with cost per project | • Coates et al. (2010) |
| RFIs Change order | • Number of RFIs /Change orders (unit)  
                          • Response delay (time)  
                          • Cost of RFIs /Change orders ($) | • Cannistrato, (2009)  
                          • Khanzode (2010)  
                          • Kunz and Fischer (2012) |
| Value (Quality of work) | • Design quality  
                          • Design labor  
                          • Design alternatives  
                          • Client satisfaction | • Kuprenas and Mock (2009)  
                          • Tillotson et al. 2002  
                          • Woo et al. 2010 |
| Quality control (rework) | • Rework Labor hours  
                          • Rework volume  
                          • Cost of rework | • Forbes and Sayed, 2011  
                          • Garrett and Garside (2003)  
                          • Khanzode (2010)  
                          • Kunz and Fischer (2012)  
                          • Kuprenas and Mock (2009)  
                          • Suermann (2009) |
| Productivity | • Dollars/unit (sq.ft) performed  
                          • units (sq.ft) per an hour  
                          • Labor productivity  
                          • Crew productivity | • Forbes and Sayed, 2011  
                          • Khanzode (2010) |
<table>
<thead>
<tr>
<th>Category</th>
<th>Metrics</th>
<th>References</th>
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<tbody>
<tr>
<td><strong>Schedule</strong></td>
<td>• Schedule productivity</td>
<td>• Suermann (2009)</td>
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<tr>
<td></td>
<td>• Subcontractor productivity</td>
<td></td>
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<tr>
<td></td>
<td>• Scheduled completion date (time)</td>
<td>• Kunz and Fischer (2012)</td>
</tr>
<tr>
<td></td>
<td>• Actual completion date (time)</td>
<td>• Suermann (2009)</td>
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<tr>
<td></td>
<td>• Latency</td>
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<td>• Field Material delivery</td>
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<td></td>
<td>• Schedule task completion</td>
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<tr>
<td><strong>Safety</strong></td>
<td>• Lost man-hours due to accidents</td>
<td>• Forbes and Sayed, 2011</td>
</tr>
<tr>
<td></td>
<td>• Safety performance</td>
<td>• Kunz and Fischer (2012)</td>
</tr>
<tr>
<td></td>
<td>• Lost time accidents</td>
<td>• Suermann (2009)</td>
</tr>
<tr>
<td><strong>Prefabrication</strong></td>
<td>• amount of prefabrication enabled by the process</td>
<td>• Khanzode (2010)</td>
</tr>
<tr>
<td></td>
<td>• actual prefabrication by each trade contractor</td>
<td>• Kuprenas and Mock(2009)</td>
</tr>
<tr>
<td><strong>Communication Behavior</strong></td>
<td>• Meeting effectiveness: agenda appropriateness</td>
<td>• Kunz and Fischer (2012)</td>
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<td></td>
<td>• Visualization use</td>
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<td></td>
<td>• Field interest in model or metrics content</td>
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<tr>
<td><strong>Organizational metrics</strong></td>
<td>• Client satisfaction and retention</td>
<td>• Coates et al. (2010)</td>
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<td></td>
<td>• Speed of Development</td>
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<td></td>
<td>• Revenue per head</td>
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<td></td>
<td>• Cash Flow</td>
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<tr>
<td></td>
<td>• Reduced costs, travel, printing, document shipping</td>
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</tr>
<tr>
<td></td>
<td>• Bids won or win percentage</td>
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<td></td>
<td>• Employee skills and knowledge development</td>
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Note: This list was partially compiled by (Barlish and Sullivan, 2012)
References


Appendix 4: CSCE Paper- BIM adoption and implementation within a mechanical contracting firm