# Impact of BIM on Electrical Subcontractors

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**Abstract –**

**The use of BIM in the electrical subcontractor community has been increasing over the past few years. The practice of using BIM for this sector varies in many ways as compared to the design profession or the use of BIM by general contractors. This study focuses on the current state of BIM implementation among the electrical subcontractors. A literature review of the topic lead to the adoption of a qualitative methodology to study the issue. The results of the qualitative study involved semi-structured interviews with practitioners in the field. The results of the interviews found that the perception among electrical subcontractors regarding the successful use of BIM varies from the general contractor. The study lead to the identification of several key themes that govern the successful use of BIM for electrical construction. The study makes recommendations to electrical subcontractors for the successful use of BIM on projects.**

**Key Words: BIM; Electrical; Subcontractor; Coordination; Field Installation; Productivity;**

## 1 Introduction

The use of Building Information Modeling (BIM) within the electrical subcontracting community continues to evolve in the United States [1]. There is an ambiguity of existing information regarding BIM usage associated with capital costs and time [1]. Returns on investment (ROI) studies often conclude that BIM is cost effective [2]. However, contrary results do exist, such as the concrete subcontractor recorded by Sawyer [3]. Sawyer [3], found that a subcontractor invested all required time and money in having a working BIM department but did not see any financial benefits. In contrast, other specialty subcontractors are mentioned within the same article and report a positive return on their investment in BIM.

Several things must be considered in the conduct of this research, the main two being time and money. Time must be considered in addition to capital costs involved. Simonian [4], conducted a survey amongst electrical specialty subcontractors. This survey revealed an ambiguity in time savings. For projects requiring BIM, more time is dedicated to creating the model and shop drawings than a two dimensional drawing method without parametric data embedded into it. However, the time put into the model decreased the amount of time required for fabrication and installation because all the details had been considered while modeling.

The time involved in coordination meetings and correcting on-site clashes must also be considered. Korman, et. al [5] outlines the traditional method of a coordination meeting and contrasts it with a coordination meeting utilizing BIM. The findings show that less time is required to resolve more conflicts when utilizing BIM throughout the coordination process. These time-saving factors also transfer into the field because more clashes between mechanical, electrical, and plumbing (MEP) systems are found utilizing BIM and are therefore prevented on the jobsite. Two main factors that are time intensive, but beyond the control of the electrical contractor, are the required level of development (LoD) and the overall area to be modeled [4].

Leite, et al [6] outlines the compounding of time required to increase a model's LoD. When progressing from a lower LoD to the next more detailed level, it may take as little as forty-five additional minutes up to eleven hours. This requirement may be beneficial to the subcontractor, especially mechanical subcontractors, for prefabrication purposes. However, if the subcontractor does not practice prefabrication, the time invested in reaching the required high LoD is virtually wasted. Therefore this factor also relates to financial benefits or detriments of BIM due to the additional modeling time potentially required.

Barlish & Sullivan [7] outline how to measure the benefits of BIM. They noted that BIM is the most helpful in heavy mechanical, electrical, and plumbing (MEP) areas. It is not uncommon for a general contractor to request a typical room to be modeled in addition to the main MEP areas throughout the building. However, general contractors do not all follow the same principles. Therefore modeling unnecessary areas to fulfill contractual requirements may also require unnecessary time.

This research is beneficial because it seeks to provide in-depth information regarding specialty subcontractor usage of BIM in relation to time and cost. The information gained from the participating subcontractors is vital to uncovering important information in this field. The two main areas in which Simonian received the most ambiguous results directly correlates to either time or financial requirements. Additionally, this study should reveal changes since the Simonian study, conducted several years ago. Since then, BIM has been used in more projects for more applications.

This research uses a qualitative methodology by conducting semi-structured interviews with the practicing subcontractor professionals. It is imperative that those interviewed have hands-on experience with the BIM process pertaining to electrical subcontractors. In order for the results to be effective to the industry, the participants must either be directly involved in the process, or be directly affected by it. By selecting these individuals, this study uncovered detailed nuances of implementation, effectiveness, and weaknesses that individuals outside the process would not be able to provide.

## 2 Literature Review

Previous research has shown that BIM is used anywhere from 0% to 90% of projects [4]. A survey conducted by Azhar and Cochran [8] found that 32% of reported projects between $10 and $100 million, 55.6% of reported projects between $100 and $250 million, and 50% of reported projects more than $250 million use BIM. BIM can currently be used for visualization, clash detection, prefabrication and on-site installation [9]. An electrical subcontractor's implementation level of BIM depends on its organizational structure [10], percentage of prefabrication [11], regular contractual obligations [7], and project complexity [12].

The trade-off to BIM implementation is modeling time and estimated start-up costs. Time may be saved in the installation phase, but at least a portion of that time is used in the modeling phase. Azhar & Cochran [8] found that 67% of survey respondents reported at least some timesavings. However, they did not report where these time savings came from, or how they were justified. Azhar & Cochran [8] also found that 67% of survey respondents reported at least some cost savings. Once again, the areas in which costs were saved are not provided.

### 2.1 Productivity

Productivity has historically had many definitions. In order to remain consistent with previous productivity studies, this research will define productivity as: "*labor productivity = output/input = installed quantity/actual work hours*" [13, pg.2]. Park et al [13] developed a productivity comparison system revolving around cost, schedule, changes, and rework. Park et al have also defined five separate subcategories of electrical subcontractor work: electrical equipment and devices, conduit, cable tray, wire and cable, and other electrical metrics. These categories were then broken down into ten different elements: panels and small devices, electrical equipment, exposed or above ground conduit, underground duct bank or embedded conduit, cable tray, power and control cable (600 volts and below), power cable (5 to 15 kilovolts), lighting, grounding, and electrical heat tracing. These are the outputs that are compared with input costs and time to determine an electrical subcontractor's productivity. However, when considering productivity as it relates to BIM for the entire company, the overall amount of work put into a project, not simply installation, must be considered. BIM generally increases site productivity but creates additional expenses during the planning phases of a project [14]. The best two measures of productivity as regards to input are time and money [13]. Time measures the efficiency of using one process over another, and money measures the direct costs associated with using that process.

BIM models are often contractually required from electrical subcontractors for MEP coordination. BIM requirements have noticeable effects to both the time involved in a project and the money required to complete a project. These are the two most ambiguous areas of productivity input to investigate. For example, time is placed into modeling rather than fixing mistakes. Money is used to employ a modeler rather than being applied to RFI work, jobsite clashes, and change orders [4].

### 2.2 Level of Development

The LoD contractually required is an expensive and time-intensive item which must be investigated. The two main questions that determine the proper level of detail are where to model and what to model. When considering which parts of a project (where) to model for productivity input efficiency purposes, the electrical subcontractor needs to consider the MEP congestion within a given area. For example, certain projects may require large amounts of the electrical systems to be modeled, such as hospitals or data centers, while other buildings may only require MEP intensive rooms and a typical room, such as a dormitory. Leicht [11], conducted a case study in Pennsylvania which laid out four main factors determining required level of development, including, "*interaction with other systems, sequence of installation, prefabrication of components, and layout considerations and density of systems*" (p. 5). Barlish and Sullivan [7], conducted a case study to determine how to measure the benefits of BIM. Within this case-study, they concluded that BIM is most helpful when utilized in heavy MEP areas such as mechanical rooms and switching rooms.

As the electrical contractor considers what to model, certain processes have an element of diminishing returns. As modeling requirements increase, the improvement to the installation process may not increase at an equal rate [11]. Additionally, Leite et al, [11] conducted a study measuring required level of detail and the returns they provided. Leite et al, found that more detailed models are considerably more helpful in coordination, but do not always increase modeling time exponentially. However, they did conclude that the level of detail should still be determined by the components' purpose and usage. Some components may be very time-consuming to model but also very easy to re-route [14]. These components would not be time or cost effective to model and should only be addressed if used for shop-drawing of pre-fabrication purposes.

Interestingly, as BIM and highly detailed models become prevalent, certain design drawings worsen [15]. In effect, the designers spend less time on the initial documents, knowing the contractors will change the initial drawings to match the installation process. This places an undue burden on the contractors to double-check existing information, fill in missing information, and eventually add all necessary installation details. Therefore the presence of accurate information received plays a heavy role in the required level of modeling detail. Finding, correcting, and replacing either missing or incorrect information is just as time-consuming as detailing existing design drawings.

Sawyer [3] conducted interviews with specialty subcontractors using BIM and discovered that in coordination meetings, what is in the model is not the problem, but what is left out may create a difficult issue to resolve and negate the efforts to conduct BIM clash detection meetings. Electrical contractors have the opportunity to either be highly efficient or sorely ineffective in the area of BIM LoD. Many areas may not require modeling and therefore should be left out for efficiency. However, certain components which are left out of the model may cause much more trouble and time to fix on the job than would have been invested in modeling it initially.

## 2.3 Clash Detection

BIM usage facilitates coordination through both clash detection methods and scheduling requirements. Savings in both time and money may be realized in this area through greater and more effective communication amongst specialty contractors and the general contractor if BIM is used to a proper level [14]. However it is possible to invest more than required amounts of time and finances towards coordination.

General contractors found a more efficient work process in the area of MEP coordination meetings when utilizing BIM [2]. Akinci and Kiziltas [2], conducted interviews with two different subcontractors over eight different projects and found that the coordination process took less time and was required to meet fewer times when utilizing BIM. Leicht [11], found that clashes discovered in coordination meetings revolve around three issues: the LoD required, a coordination issue, or a design issue. Akinci et al [14] also found that certain items should not be considered in clash detection. For instance, if a piece of 12/2 metal clad (MC) cable is clashing with a mechanical duct, that clash should simply be ignored. It would take much more time to model all of the MC cable in the office than it would to move the same MC cable in the field. Therefore, the ease and flexibility of installation needs to be considered when combing through clashes.

## 2.4 Site Installation

Site installation within the electrical subcontractor's realm operates in conjunction with the LoD translated to the jobsite. If the electrical contractor increases the model's LoD, then the site superintendents and working foremen will have more information at their disposal to properly install (output) the required components [16]. However, the translation of this information to the jobsite and the benefits thereof will vary from one company to another. It is possible that additional training is required in order to utilize the tools required to effectively translate BIM to the jobsite. Training is an additional cost and must be considered in overall company productivity. On the contrary, BIM may be just as effective for electrical subcontractors in the form of a specialized set of prints which would require no additional training.

When considering outside influences, BIM projects sometimes have a noticeable increase in the amount of information received from the Architects and Engineers [7]. The increased amount of information received helps decrease the amount of Requests for Information (RFI's) and change orders [7]. A reduced number of change orders also constitute a reduced amount of rework; rework is prevented because of fullness and transparency of information received from Architects, Engineers and coordination of subcontractors [11]. If the amount of time and money (input) placed into RFI's, change orders, and rework could be re-routed to jobsite BIM translation and prefabrication, then dollars per unit put in place would decrease due to a fullness of information. Therefore, by the definition used for this study, it will increase electrical subcontractor productivity. One study found that the implementation of BIM resulted in a reduction of time in most of the construction stages. The largest of these reductions was found within the construction phase [17]. Almost 60% of respondents reported a 12.5% reduction in schedule duration within the construction phase of a project. This reduction is contributed to the pre-solving of installation problems and a better transfer of information from the office to the field. Amongst the pre-solving of installation problems lies the use of prefabrication for site installation.

### 2.5 Construction Scheduling

Another coordination issue which currently seems to work well is BIM enabled scheduling. BIM enabled schedules help visualize overlapping scheduled activities and aid in equipment coordination [2]. Barlish and Sullivan [7] also define schedule improvements as one of the most quantifiable returns for BIM usage. One way that BIM helps improve a project's schedule is that it allows for earlier coordination meetings and faster resolutions to problem [18]. Therefore, if the coordination meeting process is investigated and a preferred method of conduct is established, then the schedule could also be improved because the amount of time spent resolving MEP coordination meetings could be applied to the overall project schedule.

Additionally BIM may help the schedule by having a 4D model, time being the fourth dimension, for differing areas or pieces of work. When creating a time-loaded model, each component or groups of components have a duration imbedded. Then a schedule can be derived using the imbedded durations for a given area or activity. However, according to the survey conducted by Eadie [19], schedule automation was listed in the last three reasons to implement BIM for any given project. BIM can be used as a visualization tool which informs the general contractor which areas can be completed first so the following sequence of operations will go as smoothly as possible. This is contrasted with attaching a time-based field within each of the BIM model objects or families. As previously mentioned in the site installation section, the majority of participants utilizing BIM found a twelve and a half percent schedule reduction [17]. Therefore, when discussing BIM enabled scheduling, the current use seems to be by the general contractor to inform the proper sequence of operations, not through a time-loaded BIM model.

The results of the literature review show that the impact of BIM within any discipline is a multi-variable, fluid target. The results could change from project to project within the same company. The main areas of investigation are as follows: main factors for BIM use, level of development, clash detection process, site installation, scheduling and modeling impacts. Based on the observations of Miettinen and Paavola [20], as well as Succar [21], the isolation of external variables is virtually impossible. Therefore, a qualitatively nuanced and inductive approach should be used to study the impact of BIM implementation in the electrical subcontracting sector.

## 3 Methodology

This research implements an interpretive philosophy. The Interpretive philosophy allows for a more situational and flexible approach to data collection. This is necessary because electrical subcontractor productivity is affected by many variables mentioned in the literature review; moreover, those variables are affected by outside influences such as: organizational structure, project general contractor requirements, proficiency in prefabrication, owner expectations, and facility management requirements, all of which are beyond the scope of this research. Due to the outside variables it would be highly unlikely to accurately compare one electrical subcontractor's productivity for a particular project with another electrical subcontractor's productivity on a different project. An inductive approach is deemed appropriate for the purpose of this research. The research strategy implemented semi-structured interviews, as a mixed method choice for a cross-sectional study. The proposed qualitative research method allowed for personal perceptions and situational knowledge to be revealed and explored. Speaking to two current employees working as BIM modelers were used as a pilot test to aid in developing questions. The refined questions were then administered via face-to-face, phone or web meeting interviews. Data saturation for structured interviews usually occurs at twelve interviews [22]. Therefore a total of twelve candidates were interviewed. The observations recorded during the interviews were transcribed and analyzed for correlations and similarities.

The electrical subcontractors considered for interview have been contractually obligated to use BIM on more than three projects. The total number of employees can range from fifty to five hundred. The target personnel interviewed were BIM modelers, BIM coordinators, and project managers who have worked on BIM projects. Guest et al. [23] found that in a sixty participant research study, over ninety percent of all codes, and over ninety-five percent of all important codes occurred within twelve interviews. Therefore, for the purpose of this research, twelve participants were interviewed. The interview results were first transcribed then coded, using open coding techniques. The codes were further consolidated as deemed appropriate. Content analysis techniques were employed in the analysis phase of the study to comprehend the data.

## 4 Results & Discussion

In performing the qualitative content analysis, six main themes were found. The six themes are: Coordination, Field Issues, Electrical Software, Current Modeling Parameters, Factors for BIM Usage, and Company Factors. Each theme describes an important aspect of the Impact of BIM on Electrical Subcontractor Productivity, and was developed by grouping similar participant responses found in the data. Within each theme are important aspects and subjects which the specific theme covers. Sub-themes helped the researchers to quantify participant responses in a comparable way. The percentages displayed note how many participants mentioned a particular idea, within the same context. Each theme and corresponding sub-themes are discussed in the sections below.

### 4.1 Coordination

The main theme of coordination covers areas mentioned about the clash detection process and subcontractor collaboration in general. The percentage of participants' responses can be seen in Figure 1. The interviews revealed that most parties involved in the BIM process during the modeling and pre-construction phase seek out and resolve joint problems with pertinent trades. It was also noted that the person running the clash detection process, commonly called the coordination leader, is a very important party with specific responsibilities that impact the entire clash detection process.

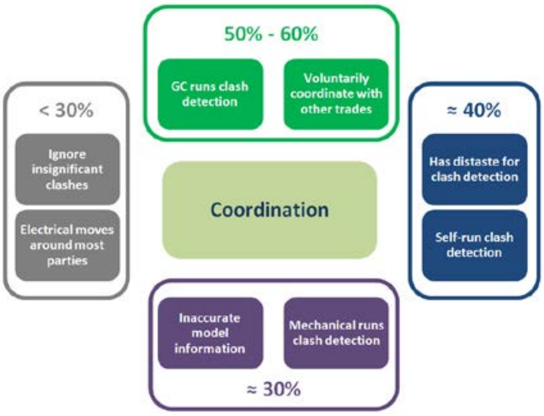


Figure 1. Coordination Qualitative Content Analysis Diagram

#### 4.1.1 Coordination Leader

The data surrounding this topic defines coordination leader as the party responsible for combining coordination models for clash detection, running the clash detection meetings, and determining who moves how far. The majority of respondents mentioned either the GC or the mechanical contractor as being the coordination leader. Only two participants mentioned the possibility of either one taking on this role.

The participants who said the mechanical contractor had to be the coordination leader never mentioned the GC in a coordination role. When both the GC and mechanical contractor were mentioned as potential coordination leaders, the GC was preferred because they have the power to force another party to move. The main power mentioned was withholding payment until requests are met.

Another factor within the coordination role is the mentality of the subcontractors involved. In certain instances, the GC has nothing to do with the clash detection process, and it is orchestrated and run by the subcontractors entirely. Within this instance, if the GC is not viable to be the coordination leader, the mechanical contractor was deemed proprietary, the one with the most to model, the party with the most at risk, and therefore should head up the coordination. The reasoning is, "*we will have to move around them anyways*," so they may as well lead.

Less than thirty percent of participants mentioned that electrical sub-contractors commonly move around other MEP trades. Their reason given is due to code restrictions for mechanical, plumbing and sprinkler locations, versus relatively few codes dictating electrical conduit locations. Therefore, it is reasonable to assume that electrical subs move around other parties on a regular basis. No participant mentioned electrical items being proprietary or having code restrictive locations. This fact makes it even more enticing to coordinate locations with other trades, because it creates less re-work for the electrical modeler in moving obstructive items.

#### 4.1.2 Voluntarily Coordinate with other Trades

The voluntary coordination with other trades takes place regardless of who the coordination leader is. It refers to a willingness to call, email, or otherwise contact another subcontractor you are clashing with outside of a planned coordination meeting. Voluntary coordination is connected to self-run clash detection and distaste for clash detection, as well as moving around most parties, as mentioned earlier.

The participants believe the clash must be cleared up regardless. As one participant put it, "*If we coordinate before the meeting and have a largely clash-free model before the meeting, then the meeting will take less time*" is a main thought. The modelers usually have multiple projects going at once, so the more work they can do in advance the better. Therefore, they will model, call to coordinate large items with other trades, run their own clash detection before upload, and clear up those clashes before uploading the model. This sequence cuts down on the overall coordination meeting time.

A long coordination meeting is one of the main complaints for clash detection. The complaint being that "*you cannot keep the modelers as you go through every little clash,*" coupled with "*sometimes the [coordination leader] is not looking in the proper places for clashes.*" Voluntarily coordinating with other subcontractors helps mitigate the distaste for clash detection, because that subcontractor would usually run his own clash detection, and therefore be required to spend less time in the coordination meeting and have less to fix afterwards.

#### 4.1.3 Inaccurate Model Information

Over thirty percent complained about inaccurate model information. One major shift in modeling expectations sends a chain reaction of field re-work down the chain of subcontractors. The shift can come from modeling omissions, unexpected site conditions, or incorrectly designed components (from any of the designing engineers). This inaccurate information results in one of two things for an electrical subcontractor: either field coordinating previously modeled components (therefore rendering the modeling a waste of time), or waiting until dead last to install whatever was either omitted or incorrect. Installing last absolutely destroys productivity because a straight run turns into a plethora of offsets and ninety's to dodge all the other systems in your way. Not to mention, it needed to be done yesterday because the ceiling crew is following right behind you.

#### 4.1.4 Ignore Insignificant Clashes

Within a clash detection meeting, the parties go through the clashes and designate who moves and how far. This note, if followed, will resolve the clash. However, every clash picked up by the clash detective is not significant. An insignificant clash would be one easily fixed in the field with little to no actual conflict. An insignificant clash would not require field re-work if not resolved. One participant mentioned that "*in a building with one thousand clashes, only about six-hundred will be significant.*" The act of going through and dismissing these clashes, according to the modelers, should be done before conducting the coordination meeting with all the trades together. Going through every clash was noted as a rookie mistake only made by inexperienced coordination leaders.

One company goes as far as saying, prior to upload, they do not even run a true clash detection in Navisworks. Instead they visually inspect what has been modeled, fix visual clashes, and continue. They took this approach because the clash detective picks up so many insignificant clashes. It is more efficient to visually inspect important clashes than wade through all the insignificant clashes.

### 4.2 Field Issues

BIM must be transferred to the field installation practices, or else, it is largely a wasted opportunity to achieve efficiency. If a model is created, but they coordinate in the field as if there was not a coordinated model in existence, then the modeling time and money was wasted. This theme of field issues encompasses how BIM is transferred to the field, and the effects it therefore has on the field (positive or negative). There were mostly positive reports given regarding BIM's impact on field installation. The respondent percentages and sub themes may be seen in Figure 2 below.

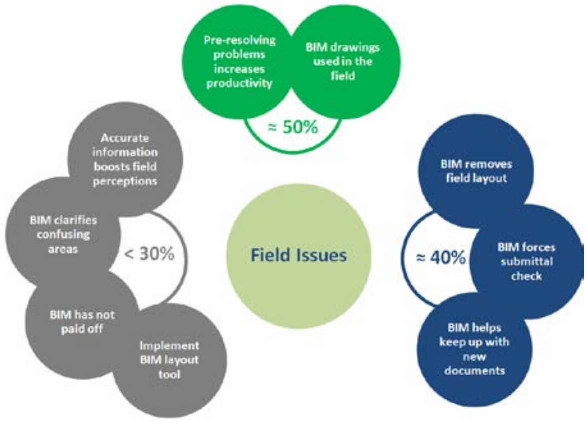


Figure 2. Field Issues Qualitative Content Analysis Diagram

#### 4.2.1 Pre-resolving Problems Increases Productivity

The pre-resolving of problems encompasses other sub-themes mentioned within the realm of field issues. The participants primarily referred to the pre-coordinated location of large conduit runs, or laid out electrical rooms. These items in turn referred to forcing a submittal check and removing field layout. They were placed into three separate categories because they are mentioned in separate locations and help explain one another. Therefore, the following discusses the idea of field layout and submittal checks.

Field layout is the act of the electrical superintendent deciding where to run the main feeders, what can be run underground, how to fit the conduits within the tight electrical room, and discerning where the main areas of confusion will be and who could help clarify these areas. While making these decisions, the field men are staring, waiting for marching orders. This is a typical, non-BIM electrical project. With BIM, the modeler, usually under the direction of the project manager and superintendent, has pre-coordinated many of these decisions. This allows the field men to begin installing conduit according to the coordinated drawings immediately. It also allows the superintendent to focus more heavily on the areas of contention and confusion. The field will still perform a level of layout, as far as measuring where items will go, however, the bulk of the decisions have already been made.

One of the most important processes of layout is ensuring that the installation components will fit within their designated areas. Usable square footage is precious, therefore non-usable areas, such as electrical rooms, are made as small as possible. If it is discovered in the field that a particular item, a panel, switchboard, light fixture, automatic transfer switch, or transformer, will not fit within its place, then your field men have to waste their time on a mistake that could have been avoided. It would be an easy fix if the project manager or superintendent simply double-checked the submittal sizes. However, as one participant noted, "*getting someone to back check submittal data when they are coordinating the actual installation of items every day is not an easy thing.*" The BIM modeler has an opportunity to ensure these items will fit before they are required to be installed. This is noted by modelers and project managers alike as a very important task. Three inches difference of a light fixture depth in a hospital corridor might as well be a mile.

The pre-resolving of layout and submittal items are the two main "*problems*" that BIM resolves and delivers higher productivity. As previously mentioned, these two items help describe the pre-resolution productivity boost.

#### 4.2.2 BIM Transfer to the Field

The efficiency with which the BIM information is transferred to the field is just as important as the information itself. The respondents described a range of BIM transfer to the field including the following: giving coordinated BIM drawings, providing specialized multi-system drawings, supplying superintendents with tablets loaded with the BIM model, training and providing BIM stations for the entire electrical crew, utilizing a BIM layout tool to establish points. The main thread throughout the entire range of BIM to field transfer is the field's ability to understand and assimilate the transfer method into their workflow. That is the main reason that over fifty percent still use specialized drawings rather than BIM-loaded tablets. The companies are certain their field personnel would not know how to properly use the BIM model. Those not making BIM available to every electrician see more benefit in having the modeler supply pertinent information to the field through paper drawings. Then, if the field has requests for more information, the modeler will provide specialized drawings or model snap-shots.

For those companies that have invested in BIM training for the electricians, the implementation of a BIM layout tool has proved greatly beneficial. One modeler reported that going into the field to lay points creates a synergy between the modeler and field personnel. It brings the modeler into the reality of what is being modeled. Simultaneously, it helps the field understand the benefit of what the modeler is doing. "*BIM total station increases morale between field men and designer because the field men see the benefit of the modeler.*" Additionally, the BIM layout tool decreases the time required for certain tasks. As clearly stated in this quote, "*using the BIM total station, they laid out a floor in one day rather than two weeks.*"

The transfer of BIM information to the field is extremely important. However, that does not automatically mean an electrical contractor should train everyone, buy all new tablets, and create BIM jobsite stations. The most important thing is for the field to use and assimilate the information. Coordinated 2D drawings that are understood would be better than a frustrated crew.

#### 4.2.3 BIM Helps Keep Up with New Documents

Construction projects, often times, release addendums and change orders throughout the duration of the pre-construction and construction phases. Having an additional person dedicated to ensuring the field has the latest and greatest information is invaluable. As noted in the software section under thematic analysis, an electrical subcontractor can be responsible for up to thirty different digital collaboration tools. It is very easy for a change to be missed, and it is crucial for the field to receive every change. Otherwise, mistakes will be corrected at the expense of the contractor. Inaccurate information is still a potential, however, an additional set of investigative eyes helps mitigate the error of outdated information.

#### 4.2.4 BIM has not Paid Off

Two participants specifically mentioned they did not feel BIM has paid off. One performs partial modeling in-house (subbing out larger modeling jobs), and the other subs out all the BIM modeling. One participant clearly stated that "*BIM is a lot of work that just hasn't paid off.*"

The only redeeming factor for one participant is that the clash detection process gets all the trades on the same page. However, he argues it is no different than the process before modeling. Conversely, he mentions a benefit in modeling within congested or complicated areas. Therefore, someone who largely opposes the BIM process still finds benefit in modeling congested areas. However, modeling the entire building is seen as a waste of time, money, and resources, which will not pay off.

Participant ten mainly claim that BIM has not paid off due to a recent project. The project performed the clash detection process and achieved a clash free model. Upon installation, design changes were made, which threw the "*entire model into chaos.*" Site coordination meetings were foregone by the general contractor in lieu of the coordinated model. This project was "*less coordinated than other projects without BIM.*" Primarily, the only redeeming factor of the BIM process is that it is a source for coordination drawings, which would have to be made regardless. Consistently inaccurate model information has convinced this participant that BIM has not paid off.

Therefore, the two main arguments that BIM has not paid off may be reduced to: we can coordinate most areas much faster in two dimensions, and inaccurate modeling information will ruin a project. Both of which are worthy points for further investigation.

## 4.3 Electrical Software

The main software dominating the electrical modeling sector are two semi-competing platforms, AutoCAD 3D and Revit. Both are owned by Autodesk, and both create geometry in three dimensions necessary for clash detection. However, only Revit is an actual BIM platform. AutoCAD 3D is a modeling program, but is not capable of having submittal data loaded into it. Figure 3 displays the percentage of participants' software preference and their opinion of electrical software in general.

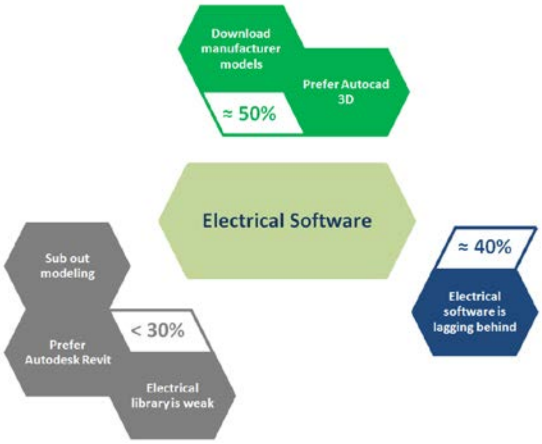


Figure 3: Electrical Software Qualitative Content Analysis Diagram

### 4.3.1 AutoCAD 3D Vs Revit

As shown above (Figure 3), the majority of participants prefer AutoCAD 3D over Revit. The main reason given is AutoCAD 3D is easier to use and more tailored to the electrical industry than Revit. Those who prefer Revit claim much of the same benefits that AutoCAD 3D users mention with the addition of manufacturer model download capabilities.

According to the proponents of AutoCAD 3D, it is a simpler program, with easier modeling procedures, and can be executed more quickly than Revit. According to one participant "*one of our operators went to school and was trained on Revit, and we trained him on AutoCAD MEP. He said the MEP for what we do is really better, faster, more tailored to what we do.*" AutoCAD is not a smart model and therefore does not require loads, circuits, or any submittal information. At times Revit is called for in the specifications. In these instances, usually the GC will allow the electrical contractor to model in whatever program they are most comfortable with and simply provide a particular export file type.

Of those proponents of Revit, two are modelers and one is a project manager. One modeler jumped straight from AutoCAD 2D into Revit, and has little to no experience with AutoCAD 3D. The other modeler has used both AutoCAD 3D and Revit. His main example of Revit's supremacy derives from being able to download manufacturer models and place them within the model. The project manager prefers Revit because of the ease of information retrieval. Revit can give you the length, size, fill, source, and destination from one click. This greatly helps in information retrieval in the field.

According to all the participants, a data loaded BIM model is a rare request. Therefore, both the AutoCAD 3D and Revit users are primarily modeling for in-house benefit and coordination purposes. That is why the selection of modeling software weighs more heavily to speed and ease of use.

### 4.3.2 Electrical Software Lagging Behind

Forty percent of participants agree that "*electrical is at the bottom of the [software] food chain.*" This is mostly in comparison to mechanical and structural contractors. The libraries are weaker, component transition is less smooth, and certain items the program may are not even electrically based. Duly noted, "*Here in a couple three years ago, the fittings the software was putting was…like using plumbing fitting or a plumbing configuration to do electrical.*"

A majority of the complaints revolved around lacking a component library. However, this was often offset by commenting on the benefit of retrieving manufacturer created components online. The other complaint was that neither AutoCAD nor Revit are actually tailored to the electrical industry. "*I can make it do what I need it to do, but there's definitely room for improvement on Autodesk's side,*" basically sums up the current standing of electrical modeling software.

One participant expounded on his contact with Autodesk in response to this room for improvement. There are opportunities to provide feedback as well as support communities. Certain support communities, at least for Revit, are monitored by Autodesk. An Autodesk representative will try to answer operational answers, or at least note a change to be incorporated into later releases.

#### 4.3.3 Sub-out BIM Modeling

Less than thirty percent of research participants subcontract out the BIM portion of the work. The primary reason for subbing out the BIM portion of a job is a lack of resources. Smaller companies do not have the additional resources to dedicate to BIM modeling in-house. In certain instances, there may be an in-house modeling department which will model certain sections of a project, but not the entire building. Although in-house modeling capabilities may be present, "*it is better to not tie up your own resources on very large projects.*"

### 4.4 Factors for BIM Usage

This main theme covers the main reasons why an electrical contractor will use BIM. The most common reason is, "because the contract requires it." However, this theme also uncovers what will be done when BIM is not required. It also helps delve into the intended primary beneficiaries of the BIM process. If BIM is not required, and certain items are modeled regardless, there is an intended beneficiary and reasoning for executing the additional work.

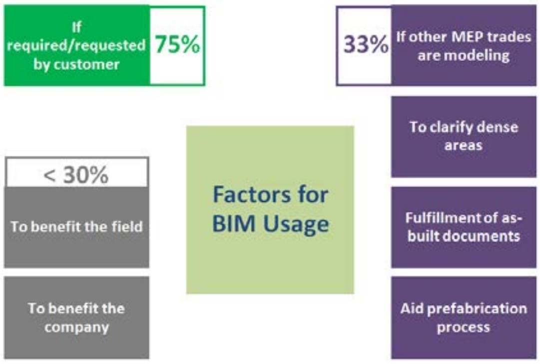


Figure 4: Factors for BIM Usage Qualitative Content Analysis Diagram

#### 4.4.1 If Required or Requested by the Customer

The primary driving force of BIM usage within our range of participants is still the owner and or general contractor. There is over a forty percent gap between those who model when required and those who model for their own benefit. The reluctance for electrical contractors to BIM a job still exists, although most participants would say that BIM has paid off. In other words: BIM has paid off when used in the most desired way. None of the project participants mentioned modeling an entire project solely for company benefit. There are always stipulations, one of the biggest currently being, if it is required?

One of the positions among subcontractors regarding the requirement is, "*this is an additional cost I need to put into my estimate.*" This especially applies to those subbing out the BIM portion of the work. If one includes the additional overhead/subcontractor cost to use BIM on a project, while another does not include that cost the contractor not carrying additional BIM charges will have a financial bidding advantage. Based on the interviews, the BIM model may cost a small percent of the entire project. In a market where a one percent change could be the determining factor between award or dismissal, documentation of a BIM requirement is crucial.

Although the same contractor may realize benefit through the BIM process, either by reduced re-work, shorter installation durations, or more field coordination, this benefit has most likely not been incorporated into the estimating programs. No participant mentioned using the BIM model for an actual bid estimate. Additionally, many modelers mentioned receiving modeling information after the project had been awarded. Hopefully, BIM savings and costs will be integrated into the estimating process, but until then, the documented requirement for BIM will likely remain the primary determining factor for its usage amongst electrical contractors.

#### 4.4.2 If other MEP Trades are Modeling

This reason did not come from those subbing out the BIM scope of work, only from those who primarily model in-house. "*If we are not required to BIM a project, the first thing I will do is call the mechanical sub and see if he is modeling.*" The primary purpose of modeling a project is coordination. There is no reason to model if there is no one to coordinate with. The model will be an added expense with no relevance to installation, and have no potential field benefits.

However, if the other MEP trades intend to model, especially the mechanical contractor, the potential field benefits remain. As mentioned earlier, there are instances where the general contractor does not require or monitor the clash detection process, and the trades do it anyways. In this instance the mechanical contractor will most likely take the coordination leadership role. As noted in the diagram, only one-third of participants are confident enough in their potential savings through the BIM process to proceed under these conditions.

#### 4.4.3 Clarification of Dense Areas and Field / Company Benefit

As mentioned under the company factors theme, at least half of the participants will conduct a post-award meeting. Within this meeting, the project manager, superintendent, estimator, and modeler will go through the project after its award. This is the meeting in which dense or potentially confusing areas will be identified for modeling. This meeting will also be the prime determinant of what exactly will benefit the field and/or company.

The primary dense area mentioned, which is also noted within the company factors theme, is the electrical room. Fitting all the gear and conduit into this room is described as "*trying to shove ten pounds of [stuff] into a five pound bag.*" Electrical rooms are the primary location where the electrical contractor will have a conflict with himself. Additionally mentioned are hospital head walls and primary corridor intersections, where multiple trades have multiple crucial components.

These are areas where questions will be left unanswered and RFI's unissued until installation. Identifying and detailing these areas before installation benefits the field by reducing re-work and limiting submittal item errors.

#### 4.4.4 Aid the Prefabrication Process

Modeling for pre-fabrication benefit is trumped by the following factors: whether BIM is required in the documents, if other MEP trades are modeling, or if modeling is determined beneficent in the post award meeting. No participant mentioned modeling for the sole benefit of prefabrication. The noted thirty-three percent of participants went into greater modeling detail, within the areas already deemed necessary to model, if it helped the prefabrication process. Therefore, prefabrication may be aided by the modeling process, but does not drive the components modeled. In compliment, the greatest benefits of prefabrication are mentioned to be within complicated, labor intensive areas. To summarize, the areas most likely to be deemed beneficial to model, will also reap the greatest prefabrication benefits. Therefore, prefabrication does not determine components to be modeled. It is an added benefit to modeling certain components in greater detail.

### 4.5 Current Modeling Parameters

Current modeling parameters would be the external factors of BIM modeling set out in the construction documents. If a project is required to be BIM, there is usually a BIM execution plan within the specifications. This execution plan varies in length, from as little as, "*this is a BIM project*," up to forty pages of details and responsibilities. This plan usually covers what to model, where to upload the model, and sets certain modeling completion benchmarks. It varies depending on owners, designers, and general contractors involved. Figure 5 below displays the commonalities amongst most modeling parameters.

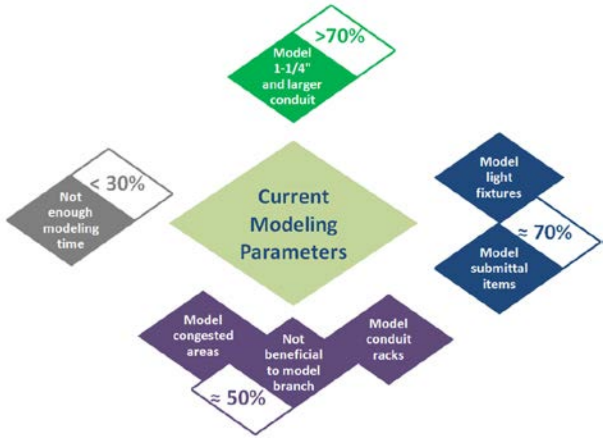


Figure 5: Current Modeling Parameters Qualitative Content Analysis Diagram

#### 4.5.1 Model 1 ¼" Conduit and Larger

The conduit over one inch is usually associated with a project's main electrical feeds located on the single line. The single line is the diagrammatic drawing showing the main power connections between power distribution items, such as: primary power entry from the utility company, primary switchgear, 480 volt panels, transformers, 240 volt panels, uninterrupted power supplies, automatic transfer switches, and certain large pieces of equipment. The feeds are usually home runs and considerably less abundant than branch conduit.

Some participants argue that modeling any feeds smaller than two inches is ridiculous. In this instance they may negotiate modeling requirements with the general requirements. However, as noted above, over seventy percent agree that modeling feeders is a beneficial component to model. One reason is that, conduit over one inch is considerably less flexible than smaller sizes, especially over two inches. Also, the wires inside the larger conduits are usually larger and can be quite expensive per foot, as well as laborious to pull. Additionally more offsets translate into more pull boxes and wire splices which also add material and labor. As one participant said, "*I can assure you, we do not want to run 6 - 4" conduits and have to move them.*" Based on other participants, that would include snaking them through other trade's obstructions.

#### 4.5.2 Modeling Light Fixtures and Other Submittal Items

This is another area that is commonly required in the execution plan, and also accepted as beneficial by the electrical contractors. Technically, light fixtures are considered submittal items, but, within the interviews, submittal items refers to special pieces of power distribution equipment, or other bulky, specialized components with longer-than-normal lead times. These are usually included on the single line.

The high acceptance of modeling light fixtures consists of two main factors: the ease with which light fixtures can be put into the model, and the drastic impact and cost just a few inches of light fixture depth can have on above-ceiling coordination. Concerning the modeling of the light fixtures, over fifty percent will turn to online manufacturer models. From that point, all they have to do is place and position. But once the modeling process has begun, the lighting package has already been scoped out and the electrical contractor has likely issued a letter of purchasing intent to a lighting vendor for their quoted lighting package. If the electrical contractor was in the field and a coordinated component did not fit due to a deeper than anticipated light fixture, the electrical contractor would be responsible for making it work. In other words, changing light fixtures to gain a few inches is an expensive proposition to the electrical contractor. And according to one participant, "*3-inches could make all the difference in a tight space.*"

Submittal items have the same issues as light fixtures, with added lead-time precautions. There are relatively few crucial submittal items in comparison to the entire electrical scope of work. However, unanticipated changes to these precious few items could quickly eat away profits and create labor down time. Akin to modeling light fixtures, modelers may find the manufacturer model for certain pieces of gear online. If not, it does not take much time to create a colored mass of the overall dimensions of the component and place it within the model. For about seventy percent or participants, the duration modeling lights and submittal items is time well spent.

#### 4.5.3 Modeling Branch

The majority of conduit in a project is branch. Branch is the connection from one device to the next in a circuit. The branch wiring is fed by home runs. These are designated as diagrammatic arrows on electrical drawings which go back to one specific panel circuit. Homeruns often run parallel to each other, and, where applicable, run down a main corridor and feed into the appropriate panel.

The modelers are not completely opposed to modeling the home runs. Blocking out this space allows for a much quicker installation within the corridor because fewer offsets and splices would be required. However, the modelers agree that once the home run reaches either the first device or the intended room, the branch modeling should stop. The argument for this is twofold. First, electrical metallic conduit (EMT) and metal clad (MC) cable are very flexible items which can be diverted around most objects. Therefore, if these components are modeled, they will simply cause an irrelevant clash, because the field man can easily divert the conduit. Second, modeling branch is an extremely laborious task with virtually no field benefits. And, if a room is reconfigured, or a wall moved, the entire branch modeling process must be re-done. Simply because fifty percent mentioned that modeling branch was not beneficial does not indicate the other half see the benefit to modeling branch. In fact, only one participant voluntarily models branch for company benefit.

### 4.6 Company Factors

Each company has its own guidelines and best practices regarding BIM usage. These factors have been compiled into the Company Factors main theme. Figure 6 displays different actions a company may take when faced with differing levels of BIM requirements.

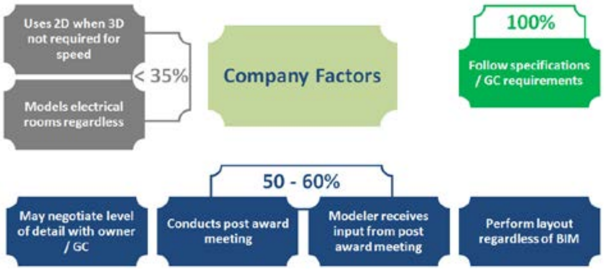


Figure 6: Company Factors Qualitative Content Analysis Diagram

#### 4.6.1 Specifications and Negotiation

Every participant was very clear that the specification documents and GC requirements were to be completely followed. It is the contractual guarantee of the electrical subcontractor to fulfill all requirements listed within the specifications and shown on the drawings. However, there are instances where the electrical subcontractor may negotiate the terms of level of modeling detail requirements.

The possibility of negotiation hinged upon the following three factors: the severity of the initial requirements, the relationship between the electrical subcontractor and the general contractor, and the type of contractual agreement (design-bid-build or design-build). The severity of the initial requirements overrules the following two factors. For instance, if the electrical contractor is initially required to model all items down to the threaded rod, he will "educate" the owner and general contractor on this time-intensive requirement regardless of prior relationship or contractual framework. Likewise, the relationship between electrical and general contractors trumps the contractual framework; positive relationships indicate a level of trust and collaboration necessary for productive negotiation.

In summary, the electrical subcontractor agrees to follow every item within the drawings and specifications. However, when the possibility to negotiate certain terms of the contract arises, particularly the modeling level of detail, fifty percent of the participants in this research capitalize on that chance.

#### 4.6.2 Post Award Meeting and Modeling

A majority of participants mentioned conducting a post award meeting. This is described as a meeting between the estimator, project manager, superintendent, and BIM modeler for the electrical contractor. After being awarded the project, they will go through the drawings and specifications. The purpose of this meeting is to orient the project manager, superintendent, and BIM modeler to the project. Additionally, this meeting is an opportunity for the project team to point out complicated areas and dictate certain components to be modeled. One participant mentioned they will "*write down what would benefit the project, or what would benefit the company as far as the BIM modeling process*" during the post-award meeting. Another uses, "*forms to determine, what we are going to do on this project, what requires modeling.*" This information is then passed and explained to the BIM modeler so it can be incorporated into the final model.

#### 4.6.3 2D Layout

As shown in figure 6, fifty to sixty percent of participants perform a level of layout regardless of BIM requirements. This layout, at a minimum, consists of drawings red-lined by the superintendent, showing where he intends to run the main components of the project. If BIM is required, the modeler will reflect the markings into the BIM model. If BIM is not required, the markings will be reflected in the 2D coordination study and taken into the field.

### 4.7 Conclusions

The impact of BIM on electrical subcontractor productivity is too recent to be objectively measured. Participants mention time savings and increases in coordination productivity. However, these measurements have not been completely quantified. Quantification is nearly impossible because of all the variables surrounding any given project, regardless of BIM. Location, electrical project manager, general contractor project manager, owner, electrical superintendent and crew, other subcontractors' managers, relationships with other subcontractors, and project complexity all play a part in electrical subcontractor productivity. However, certain conclusions can be made to the electrical subcontracting community, based on the findings of this research.

- The electrical subcontractor should try to operate under the GC as the coordination leader. If the GC is not willing to be coordination leader, the electrical contractor must should support the mechanical contractor to take up the role.
- Ensure there are no requirements to model items that have no impact on field installation. If required, negotiate with the parties requesting that level of detail.
- Give the field as much information as they can assimilate into their installation. Deliver the information in a format that enhances field personnel productivity.
- The primary areas of benefit with BIM are more thorough submittal checks, coordinated clash detection, and eases in field installation (due to prior coordination and layout). Perform these activities whenever possible and conduct an internal post award meeting.
- Coordinate with the other trades on system layout as much as possible before the BIM modeling process begins. This will reduce the number of clashes and modeling rework.
- When considering who to subcontract the BIM scope of work to, prioritize relationships and timeframes.
- The modeler should only model to an LoD for prefabrication if that area is required or beneficial to be modeled, regardless of prefabrication.
- Consideration to hire personnel who are modeling purposes must be given to those candidates who also possess field experience even if their software usage capability is not the best.

### 4.8 Future Research

This exploratory research of the impact of BIM on electrical subcontractor productivity opens the door for quantitative research in the future. The main limitation of the findings within this study is applicable due to participant size and location. It would be greatly beneficial to translate many of these findings into a widely distributed quantitative data collection medium, such as a survey.

Also, the topic of modeling timeframes seems to have the least amount of research. However, it has a great impact on coordination accuracy. It is connected with construction start dates, as well as design completion dates. The closer construction commencement edges towards design completion, the less time for underground and first floor coordination. The electrical trade is greatly impacted because the discerning what can be installed underground is largely dependent on the load requirements of the first few floors of the building. The more time between design completion and construction, the more thorough the underground installation. As underground is one of the least expensive methods of electrical installation, this could potentially lower the overall project cost to the owner. At the very least, it would help maximize electrical subcontractor profits. Although BIM may not have sufficient research to quantify financial impacts, it has the potential to significantly change the construction industry in the future.

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