

Benefits of Building Information Modeling Relative to Medical Gas Systems in Healthcare Construction

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This research explores the potential benefits and challenges of utilizing integrated Building Information Modeling (BIM) for the planning, coordination, and installation of medical gas systems within healthcare construction. In other words, what are the quality, cost, and schedule benefits associated with implementing BIM during the design and construction life cycle of medical gas systems? Research collected from a large healthcare facility project confirms that the inclusion of BIM directly relates to improved quality, decreased installation duration, and increased trade specific profit. Along with the confirmation of these results, additional cost considerations relative to BIM were identified concerning the ease and efficiency with which project materials are estimated. The relevant challenges associated with BIM were also explored as lessons learned for future projects.

Keywords: Building Information Modeling, Healthcare Construction, Medical Gas System, Quality, Cost

Introduction

Healthcare facilities are amongst the most complex facilities to design, construct and operate (Enache-Pommer, Horman, Messner, and Riley 2010). At the core of these buildings are a plethora of mechanical, electrical, and plumbing (MEP) systems running throughout the ceilings, walls, and ground competing for space to serve their intended purpose. Consequently, the efficient planning, coordination, and installation processes relative to these systems is crucial to ensure they are installed expediently, correctly, and economically. Within the last decade, Building Information Modeling (BIM) has been incorporated throughout the construction industry in an effort to better improve said processes. To clarify, The National Building Information Modeling Standards (NBIMS) Committee defines BIM as “*a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle; defined as existing from earliest conception to demolition*” (NIBS 2007). Ultimately, BIM presents new and effective techniques for mitigating steadfast obstacles within the construction realm.

On healthcare construction projects, the complexity of effective communication is a key concern relative to the various entities involved with planning and coordinating the installation of MEP systems. BIM models allow for an inclusive and collaborative relationship to take place between all interested parties, such as architects, engineers, consultants, contractors, etc. (Xie, Tramel, and Shi 2011). Moreover, when considering the installation of a specialty MEP system such as Medical Gas, the ability to proactively identify potential issues to ensure efficient and correct installation becomes a forefront objective. Consequently, BIM provides the ability to consistently and rapidly clash detect any MEP system within a facility to identify possible impediments long before any construction installation takes place. Thus, BIM provides a heightened potential to significantly improve quality, time, and cost aspects of MEP systems for healthcare facilities.

Background

Clash Detection Coordination

The conventional methods of clash detection coordination for MEP systems involves two-dimensional drawings and the Sequential Composite Overlay Process. In this process, the specialty subcontractors or the engineers develop the detailed drawings for their own scope of work, overlay the drawings on a quarter-inch scale and, using a light table, try to identify potential conflicts that might occur in the routing of the MEP systems. The conflicts are then highlighted on the transparent drawing sheets and addressed before the fabrication and installation process (Khazode, Fischer, and Reed 2008). Though extremely methodical, this strategy presents a significant possibility for human error. Moreover, due to the two-dimensional format, the percentage of potential conflicts identified is inevitably reduced leading to increased delays during construction.

As an improvement to the traditional system, the inclusion of BIM technology enables automated clash detection programs to superimpose 3D models and check for conflicts in 3D space. The 3D models from all trades are combined into a single model for automation and analyzed for clashes using tools such as Navisworks Jet Stream. The clashes are then resolved in their native programs and the iteration is performed until all clashes are resolved (Khazode, Fischer, and Reed 2008). This advancement with BIM has allowed the coordination of MEP systems to occur much earlier in construction projects. Utilization of early clash detection and coordination is now critical within the construction industry. The conflict resolution features within the BIM software provides all trades with confidence in the finalized construction drawings and clearer understanding of the project installation requirements (Riley 2000).

MEP Coordination

The MEP systems on technically challenging projects like those focused on the high technology, healthcare, and biotech industries, can sometimes comprise as much as 50% of the project value. Therefore, the coordination and routing of the MEP systems on these types of projects is a major endeavor. The MEP systems need to be routed in limited space under the design, construction, and maintenance criteria established for the systems (Barton 2000, Korman and Tatum 2001). Through the utilization of BIM, the planning and coordination of these systems during preconstruction, actual construction, and post-construction may be enhanced.

During a project's preconstruction phase, the use of BIM in MEP systems is focused on modeling, especially coordinating the elements of the models and finalizing the details. The data is not necessarily just a 3D graphic model, but generally a combination of a 3D model, 2D drawings, spread sheets, data sets, schedules, product cut sheets, etc. (Xie, Tramel, and Shi 2011). All relevant trades collaborate this information to enable proactive response to potential installation issues. During the actual construction phase of a project, the BIM MEP model may be utilized by on site personnel to visually inspect in place work and verify correct installation. As a result, the potential for human error to complicate the installation process is significantly diminished. Moreover, all MEP trade personnel may use the model as a real time planning tool to effectively direct installation sequence. Such utilization may prevent pre-mature work in place inevitably requiring re-work. The post-construction use of BIM, in particular for the MEP systems, helps to expand and compliment the economy, utility, durability, and comfort of a project. Ultimately, the detailed three dimensional virtual models are the key to make medical building projects efficient (Xie, Tramel, and Shi 2011).

Concerning MEP systems within healthcare construction, specifically medical gas systems, the benefits of utilizing BIM for planning, coordination, and execution are crucial. The strict requirements for this particular system have the potential to create a multitude of coordination and sequencing constraints relative to other MEP systems. To clarify, medical gas systems can be appreciated as life-support-systems, drug dispensing systems, and utilities to be conserved. Patient deaths have resulted from failure to adequately install, maintain, and repair medical gas systems (Dyro 2004). As a result, during every phase of a healthcare construction project that incorporates medical gas systems, strong consideration should be given to the respective requirements, parameters, and specifications. With the inclusion of BIM in every phase of such a healthcare project, the ease and confidence relative to these considerations is significantly increased.

Purpose of the Study

Strict and demanding requirements relative to medical gas systems within healthcare construction have led to the incorporation of BIM to improve relative planning, coordination, and installation. Little research has been performed to illuminate the overall impact of BIM relative to the quality, cost, and time benefits related to these systems.

Research is needed to determine the potential benefits and the necessary requirements to maximize these benefits for medical gas systems. This study investigates the advantages of integrating BIM technology within healthcare construction to achieve quality, cost, and time benefits in medical gas systems and considers the future development of BIM utilization to further enhance these benefits.

With the fierce competition that exists under the current competitive bidding system, contractors are struggling to balance their financial demands with owner demands for higher quality, lower prices, and earlier turnover (Lo, Lin, and Yan 2007). Relative to medical gas systems in healthcare construction, efficiently integrating BIM with the planning, coordination, and installation processes can significantly increase quality, decrease cost, and expedite trade duration. Moreover, these benefits may be further enhanced when combined with an entire project team willing and able to incorporate BIM into the entire building lifecycle and constructively collaborate the interrelated nature of medical gas systems with other MEP trades.

Research Design

In an effort to better understand the benefits of utilizing BIM for the planning, coordination, and installation of medical gas systems, a healthcare construction project case study will be analyzed. This facility involves both medical gas systems within its scope of work and incorporates BIM to aid in the execution of all MEP trades. The organizational hierarchy for this project includes the U.S. Army Corps of Engineers as the construction manager, Turner Construction as the prime contractor, and Midwest Mechanical Contractors (MMC) as the primary mechanical subcontractor performing installation of the medical gas system.

Qualitative analysis was executed in the form of one-on-one interviews with Turner's two primary BIM coordinators, Jeff Bauer and Joe Perkins. Mr. Bauer and Mr. Perkins both have been involved with BIM since its infancy and have seen firsthand the advantageous effects it has had throughout the entirety of their current healthcare facility project. Information relative to the quality, cost, and schedule benefits of BIM has been compiled concerning the medical gas systems within this project case study and will be presented to further illustrate these benefits.

Project Case Study

The Fort Benning Martin Army Community Hospital (FBMACH) replacement project (Figure 1) in Fort Benning, GA is a new medical facility campus for the Army Medical Command that has all the components of a technically challenging healthcare construction project. The negotiated contract for this design-build project is currently \$388M. Construction took full start in October 2010 and was completed in the Fall 2014. The project scope includes a 455,000 square foot, eight level main hospital; a 160,000 square foot, five level north clinic; and a 130,000 square foot, four level south clinic. The FBMACH includes patient exam rooms, surgery and radiology rooms, conference rooms, doctor's offices, common space, cafeteria, and specialty units such as psychiatric care, women's health, and pharmacy.

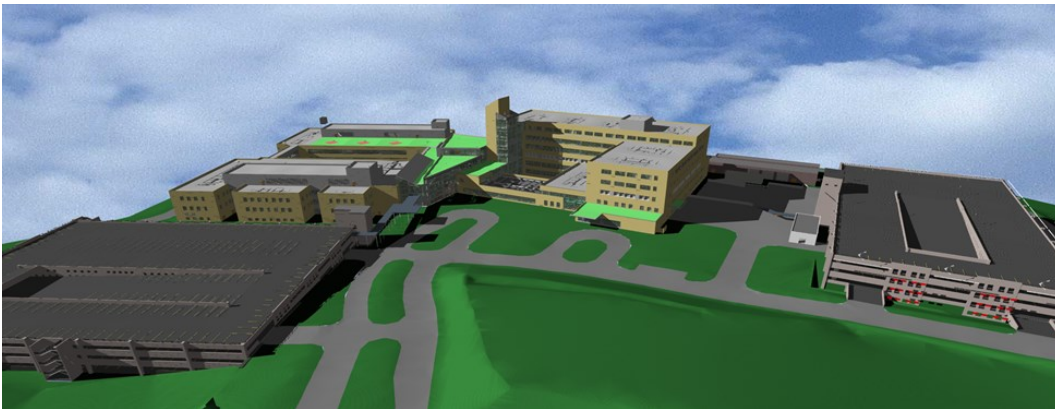


Figure 1: 3D rendering of the Fort Benning Martin Army Community Hospital in Fort Benning, GA.

Image courtesy Turner Construction GA, USA.

BIM Project Utilization

The FBMACH campus facility is designed as a steel structure with levels spanning sixteen feet from top of concrete slab to bottom of steel deck, and ceiling heights ranging from nine to ten feet. Consequently, all overhead MEP systems for the FBMACH designed to support the facility must be strategically sequenced and installed within the six to seven feet of available interstitial space on each level. As a result, the incorporation of BIM early in the life of the project was crucial to be able to identify clashes and discontinuities amongst the various MEP systems competing for space. Accomplishing this task held a learning curve at the beginning of the project that was eventually streamlined for efficiency. As told by Mr. Bauer, *“That was a phenomenon we saw here at the FBMACH. The early clash detection sessions for one floor for example may have taken us three weeks to a month to get clashes resolved to a satisfactory level. As we went through the project and got to the upper floors, it may have taken us a week to get through the same amount of clashes because the level of collaboration between the trades greatly improved allowing for better understanding of the trades relative to one another”* (Bauer 2013). Moreover, the technical information available from the BIM model for all the relevant MEP trades has proven to be immeasurably advantageous and a true confidence builder during construction installation. According to Mr. Perkins, *“From the technical side of it, at the beginning of the process, the fact that you can define such a high level of detail for each element of construction gives the confidence that what you are putting in to a particular system is exactly the part and size relative to all the parameters necessary for that system. This helps all other construction disciplines to understand individual trade needs for clearance, access, and how your system works in relation to theirs, all ahead of time relative to installation in the field. They can stick their individual BIM models into one place to look at the big picture, tear it all apart, put it back together again, tear it all apart, and so on until everything fits together”* (Perkins 2013).

FBMACH Medical Gas System

The medical gas system installed throughout the FBMACH campus facility is defined by the National Fire Protection Association as *“an assembly of equipment and piping for the distribution of nonflammable medical gasses”* (NFPA 99, 2005). Gasses incorporated within the piping distribution system include:

- Oxygen: An element that at atmospheric temperatures and pressures exists as a colorless, odorless, tasteless gas. Primarily used for respiratory therapy and anesthesia.
- Nitrous Oxide: Exists as a gas at atmospheric conditions. Capable of producing the first and second stages of anesthesia when inhaled.
- Medical Air: Exclusively used for human respiration or calibration of devices for respiratory application.
- Medical Vacuum: Primarily used for patient treatment in surgery, recovery, and ICU to remove fluids and aid in drainage.
- Nitrogen: Exists as a gas at atmospheric temperatures and pressures. Used to power instruments.
- Instrument Air: Substitute for nitrogen for powering instruments unrelated to human respiration.
- Carbon Dioxide: Occasionally used for surgical procedures and laboratory applications.
- Waste Anesthesia Gas Disposal (WAGD): Used to capture and carry away gases vented from the patient breathing circuit during the normal operation of gas anesthesia (Tinsley 2010).

The piping material for the medical gas system is hard-drawn seamless copper. Mainlines and branch lines are half-inch in diameter for pressure piping and three-quarter-inch in diameter for vacuum piping. Furthermore, drops to individual outlets are half-inch in diameter and run-outs to alarm panels and gauges are one-quarter inch in diameter. Ultimately, the parameters for this system are extremely strict allowing for very little deviation. According to the FBMACH Request for Proposal (RFP), *“The medical gas and vacuum source equipment and systems shall be installed in accordance with and meet the requirements of NFPA 99”* (FBMACH RFP 2009). As a result, the incorporation of BIM for the FBMACH medical gas system was utilized by Turner Construction and MMC to ensure the proper planning, coordination, and installation of the system.

BIM Utilization for FBMACH Medical Gas System

From the beginning of the BIM modeling process for the FBMACH MEP systems, the medical gas trade was a steadfast consideration. According to Mr. Bauer, *“From the very beginning of the collaboration and clash detection sessions between Turner and all relevant trades, the medical gas systems were involved. Their general focus was placed on where the medical gas could be racked above ceiling and that space was considered to be sacred ground as it was lower than the duct work to allow accessibility”* (Bauer 2013). Such specific location consideration was a direct result from the code and specification requirements for the system. According to the FBMACH project specifications for medical gas systems, *“The relevant contractor is to install all work so that parts requiring periodic inspection, operation, maintenance, and repair are accessible”* (FBMACH RFP 2009).

Concerning clash detection between the medical gas system and surrounding MEP trades, a systematic approach was taken during collaboration sessions between Turner and MMC to find an acceptable installation sequence for the system. The BIM model was utilized through an iterative process to find the problems and develop solutions. Figure 2 shows an illustrative diagram of the BIM model as it was utilized for a clash detection collaboration session relative to level six within the Hospital structure.

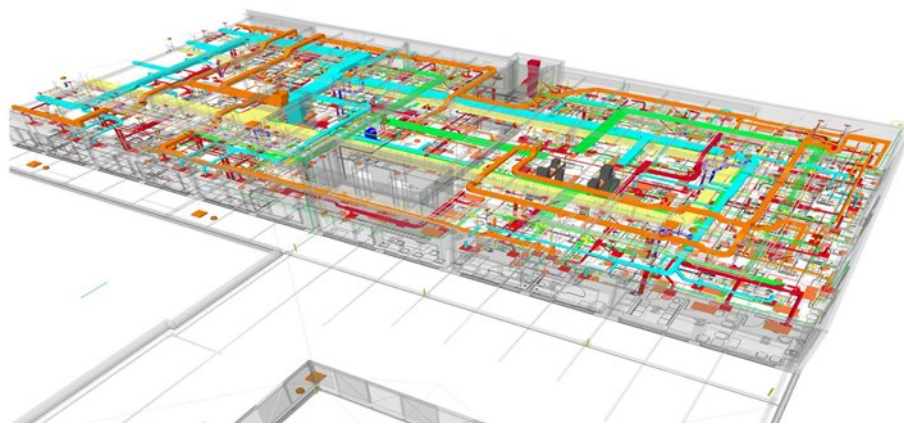


Figure 2: 3D Diagram of the MEP BIM Model for Level Six of the FBMACH Hospital Structure

Image courtesy Turner Construction GA, USA.

As can be seen, the density of the MEP systems concealed within the ceilings of the facility is extremely high inevitably creating challenging coordination and collaboration efforts to successfully incorporate the medical gas system. Mr. Bauer discussed these challenges stating, *“It was an element of space allocation just like any other system. MMC had to go through multiple iterations of positioning adjustment to fit it in with the other trades. On the bottom two floors of the Hospital they modeled the med-gas system in multiple directions until they found a path they could live with that was not impeded nor impeded other systems. The transitions where the med-gas system intersected with other systems were challenging as it created necessary adjustments, either up, down, or offset, to accommodate such intersection. After we really got rolling with the med-gas system model and started to identify the reoccurring clashes, we were able to become pro-active to prevent future occurrences. When it came to a large rack of med-gas piping intersecting another large rack of electrical conduits, one or the other was going to have to adjust to accommodate the intersection of the systems, and that typically was based on the tonnage rule. The larger the system the more directional rule it had relative to other systems”* (Bauer 2013).

Findings

Quality Benefits

The use of BIM software technology has facilitated the prefabrication coordination process and has increased the potential for prefabrication on multiple levels (Korman and Lu 2011). On the FBMACH such an advantage was maximized for the medical gas system. Instead of piecing the system together (stick-building) within the project

facility, the BIM model was utilized by MMC personnel at an offsite location to prefabricate various sections of the system. These sections were then shipped to the jobsite to be installed as modular units.

An influential advantage of the prefabrication method is decreased error and increased quality. The BIM model provided relative trade personnel the necessary information and confidence to construct the system components correctly and in a controlled environment. As told by Mr. Bauer, *“From what I’ve seen on this project, ensuring the confidence that whatever you’re fabricating is going to fit and is the right size, shape, and type is paramount. As a result, the prefabrication, especially when it’s off site, away from the actual construction, and performed in a clean environment is a direct quality benefit of BIM. Depending on the location within the project facility, there might be as many as eight trades in a ceiling, so it’s important to have full confidence that your fabrication is going to yield good results during installation. With BIM, prefabrication capabilities have improved drastically resulting in immeasurably improved quality”* (Bauer 2013). To further reinforce these findings, MMC has installed all overhead medical gas systems within the FBMACH without any necessary rework. An accomplishment directly attributable to the capabilities of BIM.

Schedule Benefits

Construction sequencing provides a complete construction schedule for material ordering, fabrication, delivery, and onsite installation of each building systems. With the integration of 3D modeling, 4D (3D model + scheduling information) is more easily generated during the project design and construction phase. Project teams are becoming more knowledgeable in their ability to link a construction schedule with individual building systems and building components to analyze proposed construction schedules and to sequence critical construction operations (Korman and Lu 2011). On the FBMACH, the project schedule was utilized with the BIM model to develop a firm understanding of when and how the MEP systems should be installed relative to each other. As a result, delivery and sequencing of MEP system materials was streamlined allowing for more efficient installation. Relative to the medical gas system, all prefabricated sections were delivered using a *just-in-time delivery* concept such that any portion of the system arriving to the jobsite would be installed within a week of its arrival. Moreover, with the clash detection capabilities of BIM, all portions of the medical gas system were installed in a systematic approach ensuring correct sequencing with all other trades and eliminating potential rework. According to Mr. Bauer, *“Having the full BIM model in the hands of our field personnel enabled them to go into the building and understand which systems needed to go in first to prevent sequencing delays. Just by the sheer visualization of the BIM model allowing the medical gas subcontractor to understand the proper sequencing of work, the amount of time saved during construction is almost impossible to quantify. It streamlined understanding enabling all trades to see the big picture and to know what the final product needs to look like”* (Bauer 2013). Mr. Perkins added, *“The increased confidence of the modeling on the FBMACH led to a more confident feeling about the project schedule and the streamlining of the sequencing”* (Perkins 2013). Ultimately, incorporating BIM modeling with the scheduling aspect of the medical gas system allowed for earlier system turnover without sacrificing quality.

Cost Benefits

The cost benefits relative to the medical gas system were not immediately realized by MMC. Accommodations for the software, hardware, and personnel necessary for the desired BIM capabilities required an upfront cost that was not budgeted. Mr. Bauer explained, *“Overall, MMC spent approximately one million dollars on just the BIM initiatives alone for the FBMACH, and the initial heartache of that price tag was hard for them to swallow as it was not budgeted to be that much. Turner asked for a lot more than they were ever accustomed to providing, and to compensate, third party modelers had to be brought in to facilitate in maintaining the modeling production schedule. However, as construction took full effect, the same individuals with MMC who expressed that heartache now say cheerfully that they made up all that cost in the field. They began demobilizing several months earlier than expected and required far less man power for a larger than anticipated portion of the project. Though they won’t share the exact numbers, they admit to realizing a return on their initial investment as well as profiting from their BIM endeavors”* (Bauer 2013). The collaborative efforts made by MMC with BIM, though initially burdensome from an economical perspective, streamlined their installation process directly resulting in increased productivity and decreased labor costs.

Discussion

Future Cost Developments

While it's evident that the utility of BIM provides the potential to realize overall increased profit relative to the planning, coordination, and installation of MEP systems, the modeling concept also presents opportunities to economically track costs directly related to these systems. The cost information contained in the BIM can be used to estimate and perform project cost tracking. Prior to fabrication and construction of any building system, the exact quantities can be determined from the model. Then using the associated data fields with an individual building component, a materials price and installation productivity rate can be applied to each system component (Korman and Lu 2011). Figure 4 illustrates this estimating capability.

While such cost estimating potential was not utilized on the FBMACH as the means necessary for Turner and MMC to execute such methods were not yet available, the significance of this estimating utility is worth noting. BIM supplies the ability to track productivity rate relative to material quantity and cost to ultimately produce real time cost estimates.

Challenges

The integration of BIM technology for the FBMACH revolutionized the planning, coordination, and installation means and methods relative to the medical gas system and all other MEP trades. An initial challenge faced as these systems began to be installed, however, was strong pushback from field personnel unwilling to change their tried and true processes and adopt the new technology. A large majority of these individuals have worked in the construction industry over twenty years and the idea of completely altering the way they have executed their profession was not initially welcomed. As the project progressed and the advantages of BIM became overwhelmingly evident, however, a shift inevitably occurred in the mentality of these individuals. Mr. Bauer explained such conversion stating, *“There is a psychology aspect to BIM in that the experienced construction personnel on jobs with twenty five plus years under their belt are initially reluctant to accept this new technology into their process. As they begin to see the power of the BIM modeling in application, however, and its ability to mitigate issues that otherwise would have been overlooked, they begin to accept the new technology as just another tool to help them get the job done”* (Bauer 2013).

To parallel these challenges faced by the FBMACH field personnel, a glaring repetitive issue encountered with the individuals responsible for modeling the MEP systems came as lack of knowledge relative to the systems being modeled. As conveyed by Mr. Bauer, *“There is one glaring issue with BIM and 3-D coordination that is going to be within the construction industry for a long time, and that is the disconnection between BIM modelers and the purpose of the systems they are modeling. These individuals do not always understand the purpose and functionality of the systems they are modeling, which leads to impractical placement and sequencing of work. The generational gap between the technically savvy modeling community and the MEP construction savvy community is evident, inevitably producing a rift between the two”* (Bauer 2013). To compensate for this problem, Mr. Bauer and Mr. Perkins increased field personnel involvement during the MEP BIM collaboration sessions for the FBMACH. The goal was to immerse the construction knowledge of these individuals within the BIM model to catch sequencing and coordination issues related to system functionality that otherwise would have been overlooked. Such inclusion also allowed the field personnel to become more comfortable with the modeling technology, inevitably aiding the solution to the aforementioned field challenges.

Conclusion

The primary purpose of this study was to determine the quality, cost, and schedule benefits of building information modeling relative to medical gas systems in healthcare construction. Analysis conducted on the FBMACH case study project revealed significant advantages to incorporating BIM within the planning, coordination, and installation processes. As discussed, a single building information model can support teamwork and collaboration during the design and construction phases of a facility (Enache-Pommer, Horman, Messner, and Riley 2010). Throughout the design and construction lifecycle of the FBMACH, the BIM collaboration aided in the quality, efficient, and cost-beneficial execution of the facility's medical gas system. Such benefits were made evident through the lack of system specific re-work, streamlined installation ability, and an increase in trade specific profit.

Furthermore, valuable lessons learned relative to challenges experienced with BIM were compiled to further enhance its utility on future healthcare projects. Ultimately, as the capabilities of BIM continue to develop, the design and construction of MEP systems will continue to be revolutionized.

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