SUCCESSFUL BUILDING PROJECT COORDINATION

Sheet Metal and Air Conditioning Contractors' National Association
4201 Lafayette Center Drive
Chantilly, VA 20151-1209
www.smacna.org

Thomas E. Glavinich, D.E.
The University of Kansas

SUCCESSFUL BUILDING PROJECT COORDINATION

SHEET METAL AND AIR CONDITIONING CONTRACTORS' NATIONAL ASSOCIATION, INC.

4201 Lafayette Center Drive
Chantilly, VA 20151-1209

Printed in the U.S.A.

FIRST EDITION – April, 2009

DISCLAIMER

FOREWORD

This document, *Successful Building Project Coordination*, is an update and expansion of an earlier SMACNA publication on project coordination. This document explains the critical importance of project coordination on commercial and institutional construction projects. Additionally, the document introduces concepts of Building Information Modeling (BIM) and how for the construction team, BIM is all about coordination

The document is intended to provide a basic orientation on the key role HVAC contractors play in project coordination. Covering coordination and project delivery as well as coordination methods, the document concludes with an introduction to BIM and a short treatment on the problematic topic of data file transfer.

SHEET METAL AND AIR CONDITIONING CONTRACTORS' ASSOCIATION, INC.

SUCCESSFUL BUILDING PROJECT COORDINATION

TABLE OF CONTENTS

1 PROJECT COORDINATION IS CRITICAL

1.1 Building System Coordination

Coordination is critical to the success of any commercial or institutional building project today. Coordination in construction once referred to simply avoiding physical conflicts in the layout of equipment in spaces and the routing of duct, piping, and raceway systems through buildings. Modern buildings require not only physical coordination between building systems but also operational coordination. It is no longer sufficient for the construction team to ensure that everything fits in the equipment room or above the ceiling. Today, the construction team also needs to demonstrate that all of the installed equipment and systems work together as planned.

For example, occupancy sensors for years have been installed in spaces to save energy by turning off lights when the space is unoccupied. In some buildings these same occupancy sensors are also being tied into the HVAC control system so that the variable-air-volume (VAV) air terminal unit supplying the space is also turned down to its minimum by the occupancy sensor when the space is unoccupied. This is a simple example but it demonstrates how once independent systems are now being integrated through common building controls.

1.2 Physical Coordination & HVAC System Installation

The HVAC contractor operating as a subcontractor on the project team or the sheet metal contractor operating as a subcontractor to a mechanical contractor (HVAC contractor) is competing for space in equipment rooms as well as above the ceiling or under the floor throughout the building with all the other building systems. Typical building systems that need to be coordinated include the following systems:

- HVAC
- Power Distribution
- Plumbing
- Fire Suppression
- Life Safety & Security
- Voice & Data Communications
- Other Specialty Systems Such As Exhaust Or Nurse Call

Central HVAC equipment is usually located in dedicated equipment rooms throughout the building as well as dedicated spaces on the roof or on the building grounds. Physical coordination is important for central heating and cooling equipment as well as the indoor and outdoor spaces that the equipment occupies. Room size and construction as well as required services such as electricity, gas, water, drains, exhaust, and others must be coordinated. Similarly, ways of moving equipment through the building and setting it, fire ratings, structural supports, sound and sight barriers, must also be coordinated. Room sizes and access must also account for HVAC equipment maintenance, major repair, and replacement.

HVAC systems serve every part of the building via ductwork and hydronic piping that is run through the building along with air and hydronic terminal units located in each conditioned building space. HVAC ductwork and hydronic piping require building space, typically above the ceiling, and compete with all the other building services for that space. As buildings become more sophisticated requiring more services and simultaneously non-occupied spaces are shrunk to improve building efficiency from both a first cost and on-going operating cost standpoints, coordination becomes much more important. The old approach to system coordination that can be summed up by "whoever gets to the ceiling space first gets it" is no longer acceptable in today's buildings. Coordination above ceilings and in chases must be based on economics and life-cycle cost of the installation. Building services such as air distribution systems whose function and operating efficiency are impacted by routing and space allocation need to take precedence over those building services whose performance is not affected by routing.

The size, shape, and routing of air ducts as well as air supply and return locations in conditioned spaces can have a significant impact on occupant comfort and building operation. Changes in horizontal direction, vertical elevation, and duct shape and size to coordinate with other building services and physical obstructions need to be avoided whenever possible through better planning and coordination both during design and construction. Nonessential air duct reroutes and changes can adversely impact the HVAC performance in a variety of ways including:

- Increased static pressure in ducts that can result in reduced airflow to zones as well as increases in required fan power resulting in greater energy use.
- Increase duct noise impacting space use as well as occupant comfort and productivity.
- Increased duct leakage that can impact space acoustics and system efficiency.
- Increased change orders during construction.

Physical coordination of the HVAC system is not only important during construction but can also affect the efficiency and effectiveness of the HVAC system over the life of the building. As discussed above, the installation and routing of the HVAC distribution system can affect the operation of the system that in turn can adversely impact system energy use, operating costs, as well as occupant productivity and wellbeing. The HVAC system in modern buildings has a significant impact not only on the first cost of the building but also the cost of operation and maintenance over the life of the building.

1.3 Physical Coordination & HVAC Duct Fabrication

Physical coordination is probably more important for the HVAC contractor than it is for any other specialty contractor on a building project. Each commercial and institutional building project is unique and so is the HVAC system that serves it. This uniqueness is particularly important to the HVAC contractor because air distribution system components that include ducts and custom air handling equipment must be fabricated specifically for the project. Prior to installation, the HVAC contractor must layout the duct in accordance with the project plans and specifications, design the individual duct components, submit shop drawings for review and approval, fabricate the duct components after shop drawing approval, and then ship the duct components to the site for installation. If anything has changed in the field or if other specialty contractors have installed their systems ahead of the HVAC contractor, there is a chance that the fabricated duct or other custom air-handling equipment will no longer fit and will either have to be field modified, shop modified, or scrapped and refabricated. Any of these outcomes that result from poor coordination will result in increased cost due to material waste and rework, shop flow disruption, lost productivity, and schedule slippage for the HVAC contractor.

1.4 Operational Coordination & HVAC System Operation

Operational coordination used to be as simple as determining whether the HVAC contractor or the electrical contractor supplied required motor starters and disconnect switches. Today, it is equally important to ensure that control devices and systems work together. Operational coordination is important for ensuring that the HVAC system operates properly over the life of the building but it can also impact the HVAC contractor's time on the project and substantial completion. The HVAC contractor needs to understand how the HVAC system is supposed to operate and what its responsibilities are regarding controls and commissioning to avoid any potential problems that may arise during the commissioning process.

2 COORDINATION & PROJECT DELIVERY

2.1 Project Delivery Systems

The project delivery system that is used on a project can impact the amount and ease of coordination on a building construction project. A project delivery system is the way that the project is organized and defines how the various project participants relate to one another and interact. In general, the following three teams are involved in any construction project:

- Owner
- Design
- Construction

The owner has the need for the project, defines the project's operational requirements in its program, and finances the project. The design team is responsible for designing a facility that meets the owner's operational and budgetary requirements and then producing a set of construction documents in the form of plans and specifications that can be used to construct the project. The construction team that includes the HVAC contractor is responsible for converting the design into physical reality for the owner through the construction process.

The project delivery system used on a project determines how these three teams coordinate with one another as well as how individual team members coordinate with one another. The three principle project delivery systems used on commercial and institutional building projects in the United States are as follows:

- Design Bid Build
- Construction Manager At Risk
- Design Build

The following sections will briefly discuss each of these three project delivery systems along with how their use can affect coordination between the teams and within the construction team.

2.2 Design-Bid-Build Project Delivery

Design-bid-build (DBB) project delivery is probably the most common method of project delivery for commercial and institutional buildings. Figure 1 provides a typical organization chart for a DBB project. DBB project delivery is very sequential with each team performing their specific work and then passing their work on to the next team to perform theirs. In this regard, DBB is very much like a relay race.

Using the analogy between DBB project delivery and a relay race can be helpful in understanding intrateam coordination. The owner starts the race by defining its needs and requirements for the facility in the form of a facility program and budget. The owner completes its leg of the race by passing the baton to the design team in the form of the facility program and budget. During its leg of the race, the design team prepares the construction contract documents based on the owner's program and budget for the construction team to build from. Once the plans and specifications have been completed, the design team passes the baton in the form of the construction contract documents to the construction team to build the project. Using the construction contract documents, the construction team then builds the project and hands over the finished project to the owner at the finish line.

As can be seen from this analogy, DBB project delivery is very fragmented. There is little opportunity for intrateam coordination during design and construction just like there is little opportunity for interaction between team members during a relay race. Each runner runs his or her leg of the race and hands the baton to the next teammate to continue the race independently. Similarly, with DBB project delivery each of the three teams perform their work and hand it off to the next team to do theirs with little or no interaction or sharing of expertise. Any missteps by any one of the three teams can jeopardize the success of the entire project for the owner. Also, what happens in the first two legs of the relay race can impact the construction team's ability to perform effectively and efficiently and there is really no way for the construction team to communicate its needs and what would help it perform better to the owner or design team during the programming and design process.

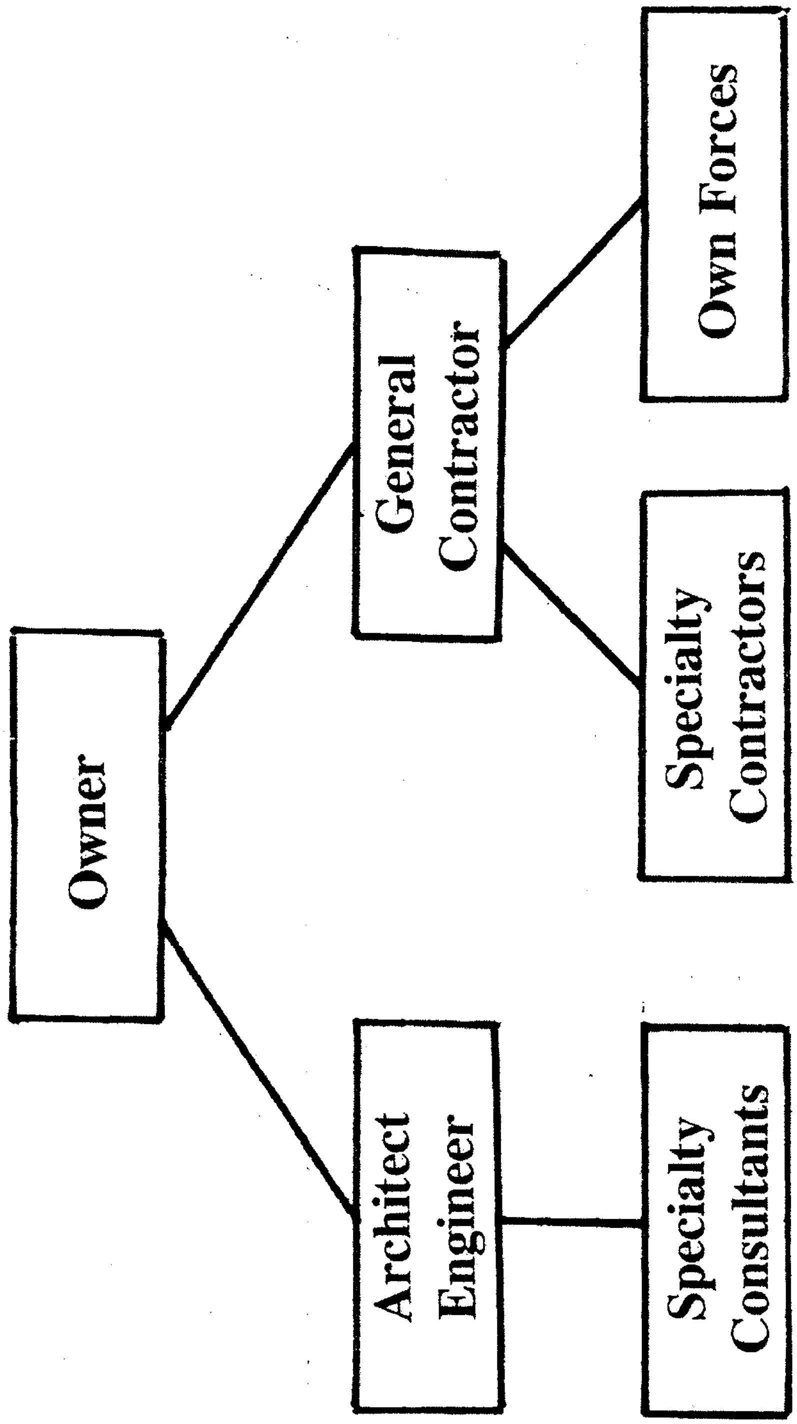

Figure 1
Design-Bid-Build Project Delivery

Intrateam coordination is further complicated by the typical method and timing of selecting the construction team on a DBB project. The designer is normally selected by the owner at the beginning of the project based solely on qualifications or a combination of both qualifications and price. The construction team, on the other hand, is typically selected on the basis of price alone after the design is completed. This is analogous to the design team finishing its leg of the relay race without knowing who it will be handing the baton off to. The owner selects a construction team from a group standing on the sideline based on which construction team says that it can complete the project for the lowest price. This would be similar to the coach selecting a runner for the last leg of a relay race based on which one says he or she can finish fastest. Like the runner, the construction team selected based on price at this point of the project can only grab the baton and run the last leg of the race as best it can.

Even within the construction team, coordination can be difficult on DBB construction projects. Like the overall team, individual team members are assigned a specific scope of work and usually selected based on price. The HVAC contractor is usually a subcontractor to the general contractor (GC). Where the sheet metal contactor is different from the HVAC contractor, it is usually a subcontractor to a mechanical contractor and a subsubcontractor to the GC. The construction agreement between the owner and the GC usually makes the GC responsible for the work of its subcontractors and overall project coordination. However, there is usually nothing other than general clauses in the agreements between the GC and its subcontractors that specifically assign authority and responsibility for physical building system coordination other than requiring that subcontractors adhere to the GC's project schedule.

As discussed previously, coordination is too critical to the HVAC contractor's success to be left to chance, a committee of specialty contractors who are each looking out for their own self interest or a GC that does not understand or care about the impact of poor coordination on specialty contractor productivity and costs, fabrication efficiency and material waste, and building system performance. The following are recommendations for improved coordination on DBB projects:

- Owners and designers need to be educated regarding the importance of building system coordination including the potential impact of poor coordination on HVAC system cost, schedule, and performance.
- The design team needs to make sure that there is sufficient space provided in equipment rooms, above ceilings, under floors, and in vertical chases to realistically accommodate all of the equipment and services required to be installed in these spaces. Spaces should be laid out considering not only the actual equipment and services that need to be installed but also access for installing the equipment and services, code requirements, space for operation and maintenance, and allowance for planned future expansion.
- In seismic zones, the design team needs to take the additional supports and bracing required by building codes into account when laying out equipment rooms, determining the depth of spaces above ceilings, and designing vertical chases.

- Construction contract documents need to address the physical coordination of building systems during construction. Plans and/or specifications should designate zones in equipment rooms, above ceilings, under floors, and in vertical chases for each building service. Building services such as HVAC air distribution systems whose performance is sensitive to routing should take precedence over building services that are not as sensitive to routing.
- The GC should take responsibility for coordinating building system installation and work with subcontractors to develop and execute coordination plans that are in accordance with the construction contract documents, meet local codes, and give precedence to those systems like the HVAC air distribution system that requires off-site fabrication and whose routing can impact system performance.
- The GC should include the specific requirements and procedure for building system coordination in specialty contractor subcontracts.
- Where responsibility for building system coordination is delegated by the GC to a subcontractor such as the HVAC contractor, the specialty contractor's scope of work and compensation should be adjusted for this additional work either in the original subcontract or by change order.
- Whenever possible, technology such as three-dimensional computer-aided design (CAD) software or building information modeling (BIM) should be used to facilitate coordination.

2.3 Construction Manager At Risk Project Delivery

Construction manager at risk (CM) is becoming an increasingly common project delivery system on commercial and institutional building projects. A typical design-build project organization chart is provided in Figure 2. One of the reasons that owner's prefer CM over traditional DBB project delivery is that CM brings the construction team into the process earlier during design so that the construction team's expertise can be used to improve project constructability and reduce costs while providing a facility that meets the owners needs and expectations as expressed in the facility program. The construction team under the direction of the CM usually consists of key specialty contractors such as the HVAC contractor and complements the design team. The construction team suggests alternative design solutions based on construction and operational knowledge and experience, performs regular design reviews, develops and keeps the schedule updated throughout the design process, and develops a project cost estimate and updates it regularly as the design progresses.

CM project delivery offers a much greater opportunity for intrateam coordination between the owner, design team, and construction team than DBB project delivery. With CM project delivery, there is still a passing of the baton in the form of the construction documents from the designer to the builder at the end of the design process but there are some major differences between CM and DBB project delivery from a coordination standpoint:

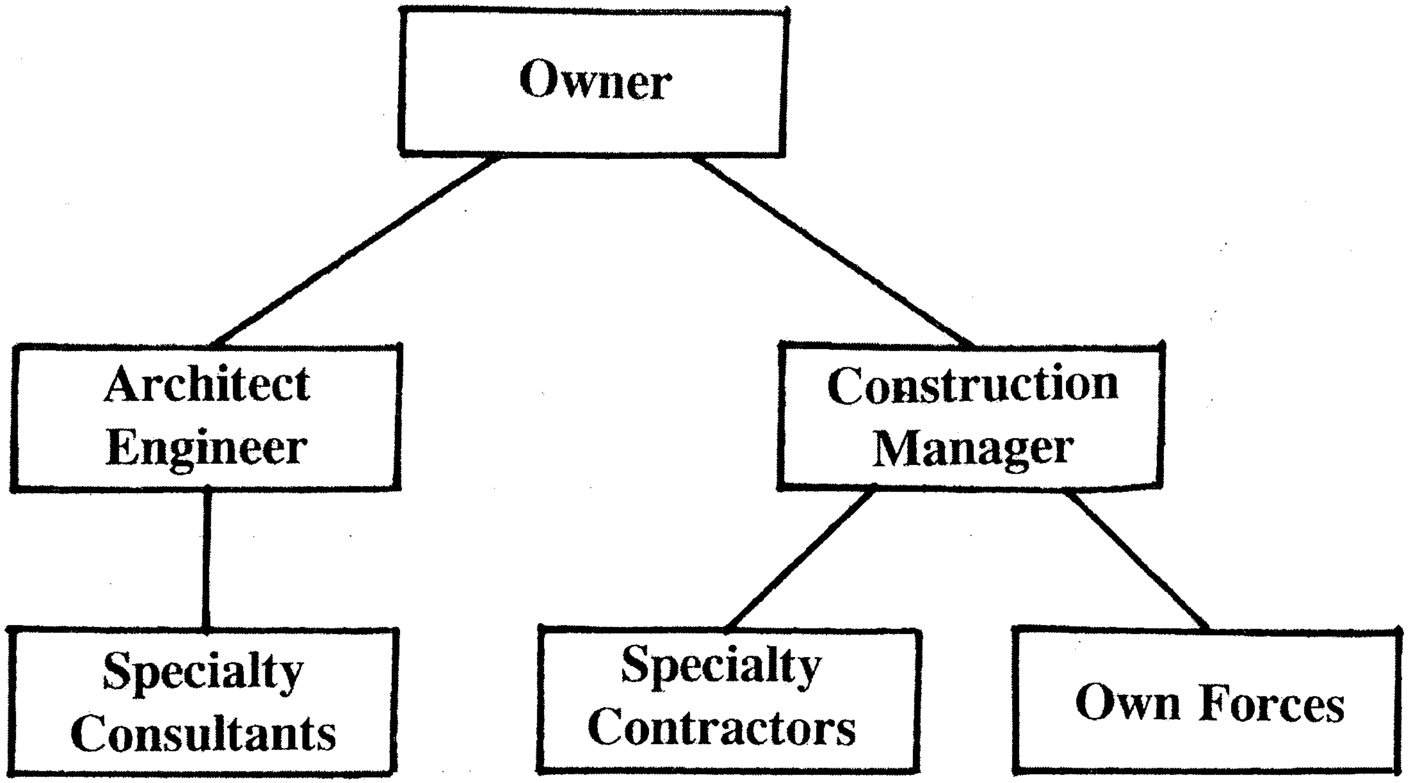

Figure 2
Construction Manager At Risk
Project Delivery

- The CM is usually selected by the owner early in the process like the designer either based on qualifications only or best value that includes consideration of both qualifications and price.
- Key Specialty contractors like the HVAC contractor are often selected by the CM early in the design process as well so that they can help with design reviews, cost analyses, and scheduling. Sometimes key subcontractors are selected based on qualifications but more often they are selected based on price from a prequalified group of specialty contractors improving the quality of the competition over DBB project delivery.
- The interaction between the design team and the construction team during the design process under CM project delivery improves building system operation coordination.
- While the design team is running its leg of the race, the construction team is running along side coaching them on how to make the next part of the race easier for the construction team. Similarly, when the construction team is running the last leg of the race after the hand off of the baton, the design team is running with the construction team coaching them on the design intent and assisting with technical problems. In the end, this interaction usually results in a project that better meets the needs and expectations of the owner because of the early involvement of the construction team.

The recommendations for the physical coordination of building system installation during construction under CM project delivery would be the same as those delineated for DBB project delivery.

2.4 Design Build Project Delivery

Like CM project delivery, the use of design build (DB) project delivery on commercial and institutional building projects is increasing. DB provides a greater opportunity for project coordination and interaction than either the DBB or CM project delivery systems. The owner only has one contract and that is with the design builder which is usually a GC or CM in the commercial and institutional building market. This is illustrated in the typical design build organization chart provided in Figure 3.

If the design and construction team members that make up the design-build team are selected by the design builder based on qualifications or best value, there is a great deal of opportunity for communication, interaction, and coordination throughout design and construction. If members of the design-build team are selected based on competitive bid by the design builder, coordination can be more difficult during design and construction than with either the DBB or CM project delivery systems. The design builder and the way that the design builder selects, structures, and manages the design-build team that the HVAC contractor is a member of is critical to the success of the project for the owner and members of the design-build team. The HVAC contractor should consider who the design builder is and how the design builder will select its project team before getting involved with a design-build project.

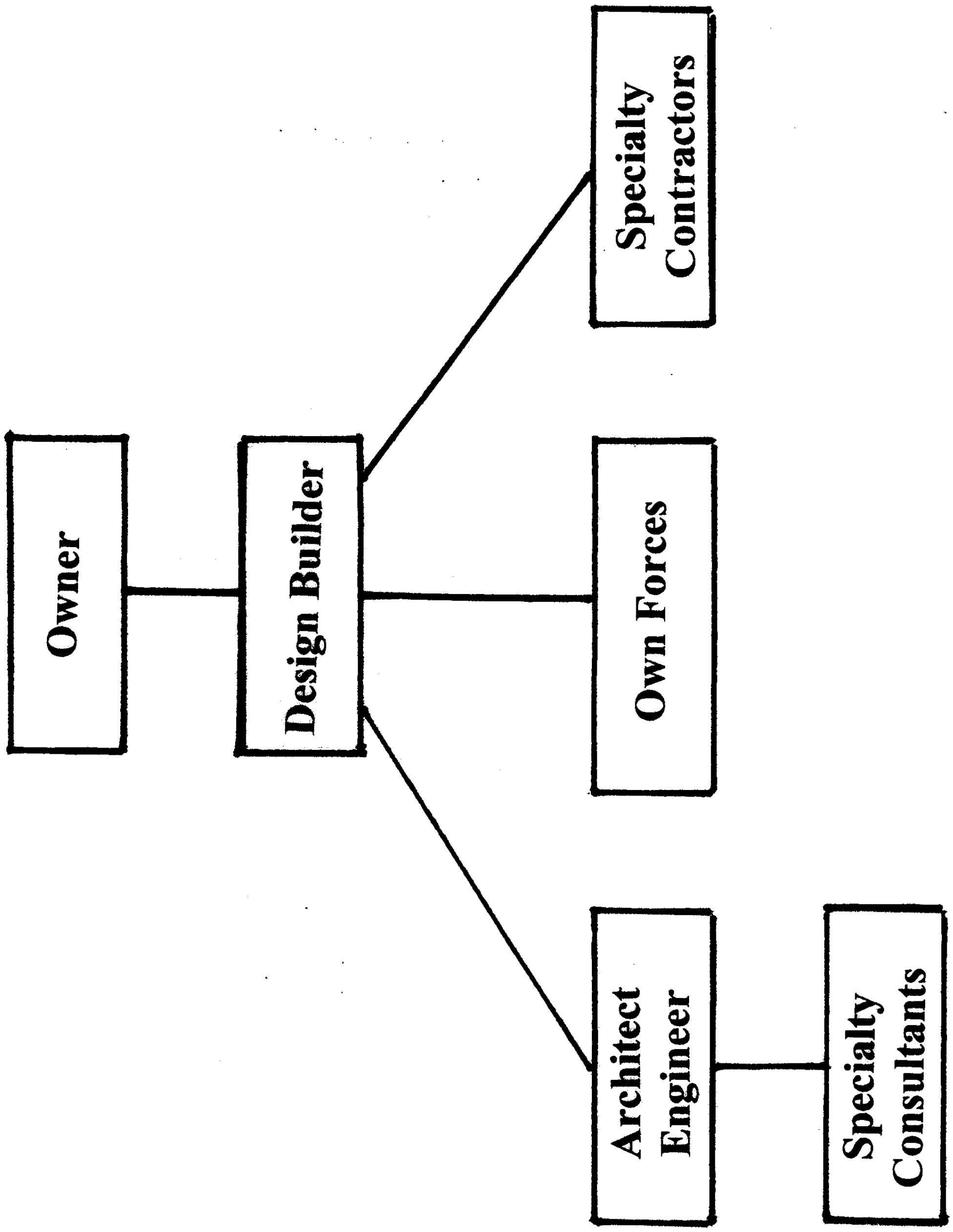

Figure 3
Design Build Project Delivery

If done right, design build can provide the owner with a facility that meets its needs and expectations for less cost, in shorter time, and with reduced owner involvement. Since all design and construction team members are part of the design-build team and involved from the beginning of the project, both operational and physical building system coordination is easier. Also, some of the barriers discussed later in this document that restrict the free flow of design information between the design and construction team using DBB and CM project delivery are not an issue with DB. All of the recommendations included for physical coordination under the DBB project delivery should be considered for DB project delivery.

3 COORDINATION METHODS [1]

3.1 Coordination Methods

Historically, there are two approaches to coordinating the installation of building services during construction. These two approaches are as follows:

- Single Coordinator
- Coordination Team

While the single coordinator method continues to be used, particularly on less complex building projects, the team approach to coordination is becoming the norm as buildings become more complex and facility services such as HVAC make up an increasingly larger portion of the construction dollar. The following sections will describe the coordination process for each of these two building service coordination methods.

3.2 Single Coordinator Procedure

With the single coordinator approach, one member of the construction team assumes overall responsibility for the physical coordination of building service installation during construction. As discussed previously, depending on the project delivery system this could be the GC, CM, or design builder. Alternately, this responsibility could be delegated to a specialty contractor member of the construction team such as the HVAC contractor. When responsibility for coordination is delegated, this delegation should be accomplished via the subcontract scope of work or change order. The coordination process for a single coordinator can include the following activities:

- Receive installation plans from all specialty contractors working in a shared area such as in an equipment room, above a ceiling, under a floor, or in a vertical chase.
- Develop a coordinated installation plan from the individual installation plans that locates all of the building services that need to be installed in the shared space and avoids conflicts.
- Based on the coordinated installation plan, prepare a work plan that includes a schedule and sequence of work for the space.

- Oversee the work as it is being performed to ensure that all specialty contractors adhere to the installation and work plans.
- Mediate conflicts and disputes between the specialty contractors working in the shared space.
- Coordinate changes that occur during construction.
- Prepare a record drawing for space as required by the construction agreement after the installation is complete.

The single coordinator approach requires participation of all construction team members that have work in the shared space. In addition, the single coordinator approach requires significant planning and coordination before work can begin in the space. Time must be allowed for this coordination work to be performed in advance.

3.3 Coordination Team Procedure

Using a coordination team, the responsibility for coordinating the installation of building services in a shared space is shared among all of the construction team members that will be working in that space. The coordination process for a coordination team would include the following activities:

- A single set of CAD drawings are developed for the space using electronic data files supplied by the design team or developed by a member of the construction team from the construction contract documents. These CAD drawings would typically be three-dimensional for this purpose.
- The coordination team decides as a group the assigned order in which the coordination work is to take place. The specialty contractors with building services that need to be fabricated and are sensitive to routing such as the HVAC air distribution system should start first.
- The drawings pass from each specialty contractor to the next in the agreed to sequence. Each specialty contractor includes its work on the shared drawings. This can be accomplished by assigning each specialty contractor a specific CAD drawing layer.
- If a specialty contractor encounters a conflict or problem with the work of a previous specialty contractor, the previous specialty contractor is contacted and the issue is resolved between them. If the two specialty contractors can't resolve the conflict or problem then all of the specialty contractors working in the shared space should get involved to find a shared solution. If the group cannot resolve the conflict or problem, the GC/CM should get involved along with the owner and/or design team where appropriate.
- When the last specialty contractor has put its systems on the common drawings, it is assumed that all specialty contractors working in the shared

space are in agreement and work can begin in the order dictated by the coordination drawings.

- If there is a conflict during installation, the conflict is worked out between the specialty contractors with conflicting installations or the group as a whole.

Team coordination is a good approach for coordinating the installation of building services in shared spaces for the following reasons:

- No one member of the project team must assume responsibility for performing overall coordination work. Also, all work is shared and no one specialty contractor is required to do an unfair amount of the coordination work.
- Each specialty contractor can focus on its own work in the shared space when it is that specialty contractor's turn to work on the shared drawings.
- Each specialty contractor is ultimately responsible for coordinating its own work.
- If one specialty contractor discovers a conflict or problem with another specialty contractor's work, the conflict can usually be resolved between these parties and doesn't require involvement of the other specialty contractors working in the shared space.

The team coordination approach works best under the following conditions:

- The order in which the work in the shared space needs to be performed is clear before the work begins either due to what has to be installed in the shared space or customary precedence of system installation.
- All of the specialty contractors that have work in the shared space are involved in the coordination process, understand the process, and are committed to making it work.
- The specialty contractors involved trust one another and are willing to cooperate with one another.

4 BUILDING INFORMATION MODELING

4.1 What Is BIM?

Building information modeling or simply "BIM" is a term that is heard throughout the construction industry today. BIM has the potential of revolutionizing building design, construction, and operation. The use of BIM on building construction projects is improving communication, coordination, and constructability.

BIM is not a software package. Many people and organizations currently equate BIM to a group of sophisticated building modeling software packages that are commercially available and used in the construction industry. These software packages are just BIM enablers that help the project team successfully complete the project for the owner. Taken by themselves, these software packages can help individual project participants such as the HVAC contractor or a select group of project participants such as the construction team better manage and use project information both individually and collectively. However, it is not until BIM is used by all parties to a construction project throughout the entire building life cycle starting with planning and ending with deconstruction that BIM's potential to optimize building design, construction, and operation can be realized.

BIM is an integrated and collaborative approach to building design, construction, and operation that all parties to a construction project participate in. Information is shared electronically throughout the design and construction process among all parties to increase coordination through collaboration and improved communication. BIM encourages teamwork and attempts to deliver the best building for the owner by drawing on the unique knowledge, skills, and expertise of all project participants that includes not only designers and constructors but also manufacturers, fabricators, and suppliers. The building information model provides a repository for project information that can be accessed and used by project participants to design, analyze, detail, price, and schedule their work.

4.2 Information Models

Information is just data organized and presented in such a way that it can be used effectively and efficiently by the user to achieve a goal or objective. An information model is just a method for organizing, accessing, and presenting the information that can be either manual or automated. Building owners, designers, and contractors deal with information models every day. For example, SMACNA's *HVAC Systems Duct Design* manual is a resource that is used by HVAC designers and contractors throughout the building industry [2]. Appendix A of this manual contains a lot of information on duct fitting losses. This data becomes information when it is used to design the air distribution system for a building. The information model in this case would be the plans and specifications prepared by the designer using this data that details the duct construction and routing. The plans and specifications that comprise the air distribution system are the information model that the HVAC contractor uses to fabricate and install the building's air distribution system.

As can be seen from the air distribution example, information models have always been used in building design and construction and are not new. These information models have traditionally been simple two-dimensional drawings and written instructions for the procurement and installation of materials and equipment. With advances in computer hardware and software, information models evolved to include building system simulation, three-dimensional drawings, and user-interactive virtual representations of buildings. Today, three-dimensional representations of buildings and building systems including HVAC equipment rooms and air distribution systems are common. Also, it is not unusual to use analysis and simulation software to design HVAC, structural, lighting, fire protection, and other building systems or to predict their performance under anticipated conditions. These simulations not only predict how the designed system will function but are also used to optimize the system performance.

Information models are not restricted to use in building design. Information models are equally important in construction and used by contractors daily. The construction cost estimate that becomes the basis for the contractor's bid and, if successful, the budget for the project is an information model. The construction activity work breakdown structure that becomes the contractor's project plan when activity logic is added and finally the construction schedule when time is included is also an information model. Site layout and sequencing plans, shop drawings and fabrication details, installation details and preplans, coordination drawings, commissioning plans and other similar information commonly developed and used in building construction are all construction information models.

For the owner, information models are used to operate and maintain the facility over its useful life. These information models are derived from the design and construction information models and include record project drawings, operation and maintenance manuals, building automation and control system programs, warranties and guarantees, among others. These information models essentially comprise the owner's operating manual for the completed building.

The above discussion of information models could apply to the HVAC system alone. However, it is important to realize that every major building system including the building envelope, structure, power distribution, lighting, fire protection, life safety and security, data and communications, plumbing, and others have a similar list of information models. For any modern commercial or institutional building there is a huge number of independent information models that are developed during design and construction for the same purpose of successfully and profitably completing the project for the owner.

4.3 Building Information Model

The design and construction industry has long recognized that all of the information models developed during design and construction for a building are related. Change something in design and it ripples through construction. Change something in construction and there is a backward ripple effect that impacts the system design performance either for better or worse. The ripple effect is usually not limited to a single system. Often a change in one building system will impact the performance and constructability a number of building systems. An obvious example of this is adding more vision glass to improve daylighting and occupant view will in turn reduce the need for artificial lighting while simultaneously increasing HVAC system load in perimeter spaces.

Project coordination used to involve using light tables and stacked Mylar drawings to detect physical conflicts and interferences when buildings were simpler. Conflict and interference analysis is still a major issue with today's complex buildings. However, equally important is identifying where the interaction of different building systems will have an unintended detrimental impact on overall building performance that could result in reduced occupant comfort, increased operation and maintenance costs, or environmental impact. The goal of BIM is to develop a single building information model that integrates all of these independent discipline- and trade-specific information models into a single relational database that can be used to improve coordination during building design, construction, and operation.

The building industry is under increasing pressure from owners, government at all levels, and the public to improve building performance. To achieve the building performance demanded by the marketplace and mandated by energy codes and standards buildings have to be fully integrated and optimized as a system. BIM is about collaboration and coordination throughout the design and construction process to deliver an integrated and optimized building to the owner. Once built, a building operates as an integrated system whether designed and constructed that way or not. An integrated building information model will allow the building construction and operation to be simulated and analyzed so that they can be optimized which can result in a lower building first cost and reduced operating costs over the life of the building for the owner.

4.4 BIM Software

As discussed previously, BIM software is the enabler that allows the building design and construction teams to integrate all of the diverse discipline- and trade-specific information models that exist today into a single integrated building information model. BIM software typically uses three-dimensional graphic building models as a basis for communicating information. This plus the fact that commercially-available BIM software packages were developed by software companies known for their CAD software has given many the impression that BIM is just three-dimensional CAD. In simple terms, BIM software is a relational database where building components are objects that are modeled as assemblies and related to one another using a predefined set of rules. These rules can be based on spatial dimensions and relationships; measurable physical parameters such as stress and strain, heat transfer, illuminance, among others; industry codes, standards, and recommended practices; manufacturer equipment physical characteristics and performance data; user preferences; and others. The three-dimensional graphic building model is just the way that the BIM software organizes and presents the database information.

Returning to the SMACNA *HVAC Systems Duct Design* manual example, all of the duct fittings in Appendix A of the manual could be designated as objects in the database. During design, when the designer selects one of the fittings and inserts it in the duct run all of the physical characteristics associated with that object also become part of that duct run including physical dimensions, material, and pressure drop. The duct fitting's pressure drop is automatically used to determine static pressure for the duct run, fan characteristics, and the volumetric rate of airflow to the space. For the HVAC contractor using the building information model, the exact number of this type of fitting for pricing and fabrication can be determined by querying the database about it. Further, if there is a physical clash between the duct and another building system due to routing or size it will be flagged for the user.

With all building components stored as objects in a relational database, it is easy for the user to extract the information from the database and have it represented as traditional two-dimensional plan views, elevations, and section cuts. The HVAC contractor is no longer limited to those plan views, elevations, and sections provided by the designer or forced to develop its own manually. Instead, the HVAC contractor can request specific drawing information that fits its unique needs. Further by querying the database about a particular object, the object's specification, shop drawings, performance characteristics, installation instructions, startup procedures, warranty, and any other information entered into the database about that object can be obtained.

4.5 BIM Implementation

Owners, designers, manufacturers, and contractors recognize BIM's potential and its use as a project coordination tool is becoming increasingly common. BIM's primary use is on complex commercial and institutional building projects but it is increasingly being used on less complex building projects as experience is gained, software proficiency increases, and the advantages of BIM are realized. Owners are requiring the use of BIM on projects because they see the value of having the building information model throughout the life of the building. General contractors and construction managers are using BIM because they see increased office and field productivity resulting from improved coordination and increased communication. As a result, general contractors and construction managers are requiring their subcontractors to use BIM as well.

For the construction team, BIM is about coordination. BIM provides a single building information model that can be used by the general contractor or construction manager and key specialty contractors throughout the construction process. Ideally, the base model would come directly from the design team as electronic data files that can be used directly by the construction team to plan, price, and schedule the project. Unfortunately design team concerns about design ownership, professional licensing issues, and professional liability sometimes limit the construction team's access to the design team's electronic data files. These concerns include access to two-dimensional and three-dimensional CAD drawing files as well as BIM files when BIM software is used. As a result, contractors are using the design information provided in their contract documents to develop their own building information model.

Contractors developing their own information model from the project contract documents is not new. HVAC and sheet metal contractors, structural steel fabricators and erectors, precast concrete and curtain wall fabricators, and other specialty contractors that fabricate materials have always prepared their own detailed shop, fabrication, and erection/installation drawings based on the contract documents supplied by the design team. The difference with BIM is that instead of having multiple independent trade-specific information models, there is only one overall building information model that is used by the entire construction team.

The construction team's building information model is currently developed in a variety of ways. Where the general contractor or construction manager has the in-house capability to develop the building information model, the general contractor or construction manager can develop the model from the construction contract documents and then maintain it throughout construction for the construction team. Alternatively, a fabricator or specialty contractor that would normally develop a three-dimensional building model as part of their work would have the development of the original building information model included in their scope of work. After the initial building information model is developed by the fabricator or specialty contractor, the general contractor or construction manager usually takes over responsibility for managing and maintaining the model for the construction team although the original model developer could do this as well. Finally, an outside design or construction consulting firm could be retained by the construction team or an individual contractor to develop and maintain the building information model.

4.6 BIM Uses

The building information model can be used by the HVAC contractor in a variety of ways throughout the construction process. Some of these uses include:

- Material Takeoffs, Cost Estimating, & Bidding
- Constructability & Value Engineering Analyses
- Determining Construction Means & Methods
- Planning & Scheduling
- Material & Equipment Procurement & Expediting
- Fabrication
- Change Analysis & Pricing
- Commissioning & Closeout

From the above list it can be seen that there may be advantages for the HVAC contractor to develop its own integrated building information model at the beginning of the project and use it throughout fabrication, installation, and commissioning even if the rest of the construction team is not using BIM. The cost of the original model development may be offset by increased efficiency and accuracy in performing the above activities including the preparation of record drawings, commissioning reports, sustainability certification documentation, and operation and maintenance manuals for the owner at the end of the project.

4.7 Expanded BIM Use

Building owners that retain and operate their buildings see the advantages of having an accurate integrated building information model that can be used to monitor and analyze building performance, as a basis for building modifications and renovations, and for building operation and maintenance. As a result, private and public building owners are requiring that building information models be used on their projects by design and construction teams by contract. Designers and their professional associations and societies are working with intellectual property attorneys, state licensing boards, and professional liability insurance carriers to work through their concerns about using a common electronic building information model for both design and construction.

Equipment manufacturers are providing product information in an importable format that can be used directly by BIM software without the design or construction team having to build a model for each piece of equipment used. Also, the developers of building system design and analysis software are making their software compatible with BIM software so that needed input data can be extracted directly from the building information model, processed by the design or analysis software, and injected back into the building information model without user intervention. Similarly, construction estimating, scheduling, management, and accounting software providers are developing seamless interfaces with BIM software as well. Eventually, the impact of changing the size or location of a structural member, increasing the size of a fan motor, adding a variable-air-volume air terminal unit, or any other change will be known almost immediately along with the change's impact on other building systems.

4.8 Getting Started With BIM

Most HVAC contractors currently use CAD to develop final equipment room and duct layout, develop shop drawings for designer approval and fabrication, and for preparing detailed installation drawings for the field. As noted above, BIM software is not a simple extension of three-dimensional CAD software even though the same software firm may have developed both packages. Similar to converting to a new estimating system, users need to be trained, objects need to be developed to describe equipment and fabricated materials, rules input, and standard output formats specified. For any designer or contractor, the conversion from CAD to BIM requires an investment of both time and money.

The first step in getting started with BIM is to understand the advantages and potential payback that converting to BIM can have for your firm. Also, survey your market to find out what the general contractors and construction managers are doing in this area as well as the owners, architects, and engineers that your firm often works with. Unlike an estimating or accounting software package that your firm might adopt, BIM software is about collaboration and whatever you choose will necessarily need to be compatible with what your clients and their clients want to use. Lastly, when you do convert to BIM software, take time to understand its capabilities and how you can improve your existing project management, fabrication, and installation processes and reengineer these processes to take full advantage of its capabilities.

5 DATA FILE TRANSFER

5.1 Data Transfer Need

The ability to send and receive data files electronically is a must for the HVAC contractor today. Bid packages, construction contract documents including drawings and specifications, shop drawings, and many other documents are increasingly only available electronically. Physical plan rooms are giving way to electronic plan rooms where bid documents are only available for downloading. General contractors and construction managers, architects and engineers, and owners increasingly want to exchange documents electronically rather than physically.

The ability to almost instantaneously transfer data files to the consulting engineer down the block or the manufacturer half way across the globe is amazing. This ability to electronically transfer any type of electronic file via the Internet saves the HVAC contractor both time and money. This ability to rapidly transfer data files in an instant to anywhere in the world can improve coordination and communication and avoid delays and miscommunications.

5.2 E-Mail Data File Transfer

The most common and simplest way to transfer a data file is to attach it to an e-mail message. This works well for small to medium size files but larger files may be blocked by e-mail providers, Internet service providers (ISP), or the sender's or recipient's own information technology (IT) group for a number of reasons. Therefore, attaching drawing files, large documents such as project manuals and reports, photographs and videos showing actual site conditions, construction schedules, design and analysis program input and output, and other large files to e-mail messages may not be a viable method of electronic information transfer.

5.3 Data File Conversion

Where the data file recipient does not need access to the file in its native format, the file can be converted into a read-only portable document format (pdf) file prior to sending. Any file that can be printed can be converted into a pdf file including drawing, photograph, and text files. A pdf file is usually smaller than the file in its native format and can often be e-mailed after conversion. In addition, firewalls that will routinely block files in their native format will often let pdf files through.

5.4 Data File Compression

When the recipient of the electronic data file needs to have access to the file in its native format, file compression software can be used to reduce the size of the file so that it can be attached to an e-mail. There are a number of data compression programs available and compressing these files using these programs is often generically referred to as "zipping" them. The "zipped" file is then sent as an e-mail attachment and when it is received the recipient "unzips" the file and it is ready to be used.

Zipping files can reduce the size of even very large files to a size that can be sent as an e-mail attachment. However, the sender must be willing to zip the file before transmitting and the recipient must be willing to unzip the file when it is received. If the file is not available in zipped format or if the sender is not willing to zip it for the HVAC contractor, then the HVAC contractor will need to find another way of getting the needed electronic information. Similarly, if the recipient is unwilling or unable to unzip a data file sent by the HVAC contractor then the HVAC contractor will need to find another way of sending the data file. Also, both the sender and recipient must have the same data compression program and know how to use it. Another downside to data compression is that even when both the sender and recipient are using the same data compression software, the file may be corrupted either by the process or during transmission which means the whole process must be repeated.

5.5 Establishing An FTP Site For Data File Transfer

One way that the HVAC contractor can avoid the limitations associated with trying to transfer large data files as e-mail attachments is to establish an FTP site. An FTP site is essentially a computer operating as a server that allows uploading and downloading of files using the file transfer protocol (FTP) over the Internet. FTP works essentially the same as hypertext transfer protocol

(HTTP) used to download web pages or simple mail transfer protocol **(**SMTP) used to send e-mail over the Internet. The only difference is that the data file is transferred as is using FTP and not translated by the user's web browser or e-mail program. All three of these applications use the Internet's standard TCP/IP protocol for transferring data.

An FTP site is like a file on your computer desktop in that you can upload, store, and download any type of data file. In addition, anyone with access to the Internet can also access the files stored on your FTP site eliminating the need for you to e-mail them to the recipient. To access the FTP site, the recipient needs to have a user identification and password that you supply to them. To download a file from your FTP site the recipient usually only needs a web browser.

FTP sites can be set up and maintained by you or there are FTP site hosting services that you can use for a monthly fee similar to a web page hosting service or ISP. In fact, your current web page host or ISP probably offers FTP hosting services for an additional monthly fee. When setting up an FTP site you should also work with your hosting service to make sure that your site is secure.

6 ACTION PLAN

Project coordination has always been critical to the success of any building project. However, today's building projects are becoming more complex at the same time that owners are demanding increased construction quality, reduced construction schedules, and tighter construction budgets. This is requiring the construction team to become more efficient and innovative than ever before and making project coordination more important to project success. This is especially true for the HVAC contractor whose system is prefabricated, requires a significant portion of shared building space for routing, and is very sensitive to field changes and reroutes.

Effective project coordination is too important to the HVAC contractor to be left to chance or another member of the construction team that does not understand its importance to the HVAC contractor's project success. In today's complex buildings, project coordination needs to be a team effort that involves all of the key specialty contractors on the construction team that have a vested interest in shared routing and equipment spaces as well as the interoperability of principle building systems. The HVAC contractor needs to be proactive and take a leadership role in the team coordination effort.

As in other areas of the HVAC contractor's business, information technology (IT) can make the coordination process more collaborative and efficient. Building information modeling is being used by owners, designers, and contractors to improve the design and construction process as well as the operation of the completed building by the project owner. The HVAC contractor should investigate how BIM can be used to increase the efficiency of planning, fabricating, installing, and commissioning the HVAC system as well as coordination with others. To begin to get involved in using BIM, the HVAC contractor should build on its experience with 2D and 3D CAD as a planning and fabrication tool and take the following steps toward making BIM a part of its everyday business:

- Understand the advantages and potential payback that converting to BIM from CAD will have for your firm.
- Survey your market to find out what the general contractors and construction managers are doing in this area as well as owners, architects, and engineers.
- Make sure that any BIM software you are considering is compatible not only with your clients' systems but that it is also compatible or will be compatible with your own internal accounting, estimating, scheduling, fabricating, and other software systems.
- Take time to understand how BIM can improve not only project coordination but also your entire business. Don't make the mistake of merely adopting BIM to your existing business and production processes. Instead look at how the use of BIM's capabilities can be used to improve your overall business.
- Make an investment in training for everyone in the firm that needs it. Don't skimp on training and understand that there will be a learning curve in the adoption of BIM.
- Lastly, make your investment in BIM pay off. Actively market your capabilities to clients as well as look for ways that the use of BIM can improve your internal business and production processes.

7 REFERENCES

[1] John F. Hill & Michael P. Ingardia, *Project Coordination: Everyone Can Win When It's Done Right*, Sheet Metal and Air Conditioning Contractors' National Association, January 1998.

[2] Sheet Metal and Air Conditioning Contractors' National Association, *HVAC Systems Duct Design*, Fourth Edition – December 2006.

8 ACKNOWLEDGEMENT

The author would like to thank the members of the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA) HVAC Contractors Council Steering Committee for their assistance in the preparation of this manual.