CHAPTER 57

INTEGRATED BUILDING DESIGN

INTEGRATED building design (IBD) is a collaborative process of preparing design and construction documents that result in optimized project system solutions. For IBD to succeed and be beneficial to the project, the entire project delivery team must be committed to, understand, and remain engaged and involved in the process from project inception through operation and maintenance.

This chapter provides a working knowledge of IBD, highlights activities that support collaboration, and helps the HVAC design professional develop a structured and integrated approach to project delivery. The basic process framework is outlined, and major milestones are identified.

The resources in the References and Bibliography, as well as other Handbook chapters and ASHRAE guidelines and standards offer in-depth guidance on various IBD application requirements and should be referred to for more information.

PROJECT DELIVERY

Delivery of solutions in the built world is accomplished in many ways and through various delivery techniques. Whether it is design-bid-build, design-build, design-construction manager (design-CM), etc., each delivery method requires interaction between design professionals representing inclusive elements of the project.

Sequential Design Process

In a sequential design process (SDP), elements of the built solution are defined and developed in a systematic, sequential, and somewhat isolated process. As each element is resolved, a new element is added to build on the overall project solution. A typical SDP can be briefly outlined as follows:

1. The architect develops the building program and proposes a facility layout to support the program.
2. Trade budgets are set to comply with the overall construction budget.
3. The structural engineer defines the skeleton to support the proposed facility.
4. Facility services engineers are given the proposed layout, structural system, and trade budgets, then directed to apply mechanical, electrical, and plumbing (MEP) solutions.
5. Discipline design evolves on individual paths to support the allocated trade budgets.
6. Coordination impacts are shared with the project team.

Integrated Design Process

An integrated design process (IDP) discourages sequential philosophy and promotes holistic collaboration of the project team members during all phases of project delivery. Emphasis is placed on optimizing system solutions that are responsive to the objectives defined for the project. Optimizing system solutions requires the participation of all team members.

Effort Shift

Execution of the IDP requires a departure from conventional SDP methodology. This change includes a true shift in effort during the classical design phases (schematic design, design development, and construction documents), but also includes the addition of enhanced efforts outside the traditional design phases.

The classical design phases promote a certain level of SDP based on their inherent percentage development model. SDP typically unfolds along the following development path:

1. During the schematic design phase, the basic form and function of the facility are defined to meet the program. Facility services are described in concept to support the developed facility construction.
2. During the design development phase, systems proceed in parallel development paths to find best-fit solutions that meet the project budget and provide compliance with prescribed regulatory requirements such as building, life safety, energy, and ventilation codes. Life-cycle cost activities (LCCA) may be used to optimize individual discipline solutions in response to the schematic design development package.
3. During the construction document phase, all building components are detailed into work results suitable for procurement and construction.

Integrated design alters this traditional delivery model by front-loading collaboration efforts to optimize building system solutions in response to the defined project objectives. Integrated design is most effective when key issues are addressed early in design and planning (see Figure 1). An important point to remember is that implementation of the IDP does not necessarily mean getting more things done early; it means getting the right things done early. To accomplish this, traditional team roles that lagged early design activities must participate on equal footing earlier in the process, so that holistic issues are considered before it becomes too late to effect responsible inclusion.

OBJECTIVES

IDP is accomplished by responding to project objectives. These may be defined by the owner before team selection, or developed by the project team during any project phase. The key is to define substantive objectives that can materialize into practical, constructable results. Prominent objectives are outlined in this section. Definitions of objectives in the IDP are only highlighted here; consult application-specific material when considering the effects of each objective.

The preparation of this chapter is assigned to TC 7.1, Integrated Building Design.

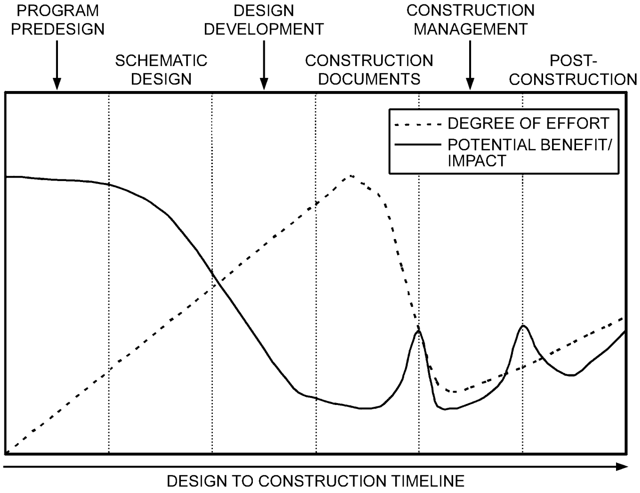

Fig. 1 Benefits of Early Design Collaboration
(Lewis 2004)

Various organizations and owner entities have developed sustainable, green, and high-performance prescriptive point systems to promote select project delivery objectives. Typically, these point structures address sustainable sites, water efficiency, energy and atmosphere, materials and resources, and indoor environmental quality. Although incorporation of these objectives is a highly desirable pursuit and promotes responsible environmental stewardship, the team must realize that desired accumulation of points in a prescriptive rating system should not shift focus from meeting the defined project objectives.

Energy Use

Energy performance objectives can be as simple as providing minimum prescriptive energy code compliance, or as detailed as providing a net-zero-energy performance facility. The extent and complexity of the objectives must be tailored to each individual project. Sample objectives that may be encountered include the following:

- Provide minimum prescriptive compliance per applicable energy code requirements
- Improve energy performance by an owner-defined percentage beyond applicable energy code benchmark(s)
- Provide a facility site energy density of less than owner-defined consumption per unit area
- Provide a facility source energy density of less than owner-defined consumption per unit area
- Provide owner-defined percentage of facility’s source energy from renewable resources
- Limit owner-defined percentage of facility’s source energy to nonrenewable or consumable resources

Typically, energy-related objectives address consumption, efficiency, and generation (site and source) issues. There are a myriad of variations, combinations, and themes that objectives can take regarding these factors. These combinations serve as an excellent example of why the underlying objectives for the project should be fulfilled before performance-rating-system point tabulation becomes the primary focus.

Indoor Environmental Quality (IEQ)

IEQ objectives vary with the programmed use for the building. Each aspect of IEQ must be considered.

Acoustical comfort may require specific focus because of the nature of activities inside and around the facility. Theaters, for example, have certain prescribed noise criteria that must be provided to allow for intended operation. Achieving prescribed noise criteria for specific building operations requires knowledgeable collaboration by all parties that control the source noise, transmission paths, and measured point of sound pressure.

Depending on the facility, **thermal comfort** may or may not be a critical objective. The project team needs to clearly understand the individual facility thermal conditions and the range of acceptable variation. This criterion has a significant effect on the size, type, and complexity of potential infrastructure solutions.

Depending on the climate and operational needs, **humidity** or **moisture control** may be an appropriate objective. This objective can be further expanded to address building protection, occupant comfort, or process needs.

Ventilation effectiveness deals with the practical and reliable means of providing ventilation air into the breathing zone of the facility occupants. Table 6-2 in ASHRAE *Standard* 62.1 identifies zone air distribution effectivenesses E_z ranging from 0.5 to 1.2 for various air distribution configurations. An objective that may be defined is to limit HVAC solution configuration to systems that provide an E_z value of 1.0 or greater.

Visual quality can be a concern for certain operations. The quality of ambient light in a space can have direct effect on occupants’ productivity. Properly applied and controlled, daylighting can improve the visual quality of the occupied space and reduce the capacity of the HVAC systems by decreasing the need for artificial indoor lighting systems.

Water Usage

Potable water is essential to life and faces continuous pressures relative to availability and quality. IBD objectives for water usage typically focus on conservation and reclamation efforts. Water has a cost associated with its use. This use should be modeled in the total ownership cost of a facility.

Conservation and reclamation of water do not apply only to plumbing systems. HVAC systems can consume significant amounts of water and are prime candidates for environmentally responsible project objectives. Sample objectives that have an HVAC influence include the following:

- Reclaim all cooling condensate discharge for use in gray-water systems. Note that reclaimed gray water can be applied to a host of facility service applications, such as cooling tower makeup, landscape irrigation, urinal flushing, etc.
- Capture all facility storm water drainage for use as gray-water makeup for HVAC, plumbing, and landscaping needs.
- Increase concentration limits and/or decrease cycles on cooling tower blowdown to conserve water consumption. This, of course, must be balanced against the suitability of an integrated maintenance program and limited to local water quality characteristics that contribute to scale, corrosion, fouling, and microbial growth.

Vulnerability

Global events and operational needs may dictate that built solutions address vulnerability objectives. The facility infrastructure may require protection from outside seismic incidents, blast events, or chemical and biological contamination. Inside operations that create explosion, chemical, biological, or radiological hazards may require focus. Additionally, protecting occupants in the facility may be an inclusive or standalone priority. In any case, vulnerability objectives create some challenging opportunities for collaboration and demand that the project team have an effective prioritization system in force on the project. See Chapter 58 for more information on the topic.

Environmental Stewardship

Waste reduction is a pressing need in the built world. The capacity of landfills to absorb construction debris is not limitless. Reuse and recycling of construction debris can help mitigate landfill overuse. Also, when materials cannot be harvested or obtained from the project site, using new construction materials that include recycled content is a proactive consideration.

As concerns with global warming and greenhouse gases increase, minimizing the carbon footprint of the facility may become a critical objective. This will require a unique collaborative effort to minimize the sum of the embodied energy and carbon emissions of all processes and components required to construct, own, operate, and maintain a facility.

Critical Operations

Certain objectives are critical to operations for data centers, emergency response, law enforcement, government, health care, shelters, manufacturing, and pharmaceutical facilities. For example,

- Facilities that require high reliability must focus on ensuring that systems and components meet the specified probability they will operate for the duration of use. As the required reliability increases, infrastructure design must respond in kind with system redundancy and diversity.
- Facilities that require high availability must focus on ensuring that systems and components meet the specified probability they will operate and be accessible when required for use.
- Scalability may dictate that infrastructure have provisions for expansion and growth relative to dynamic business factors and technology development.

General Operations

Accessibility priorities may dictate that some infrastructure have unique requirements to ensure proper performance and serviceable attention during the operational life. Accessibility has an infrastructure cost effect that must be factored into the total ownership cost.

Replaceability objectives may define where facility infrastructure can be located so that replacements can be made when the useful life has expired. Total ownership solutions should plan for the costs to replace equipment and not leave this as a hidden burden for the facility owner to bear later.

Many owners face a dynamic known as churn (reconfiguring a space or changing its use). Objectives that plan for churn can help mitigate complete replacement of facility services if changes need to be made.

TOOLS

IDP requires detailed simulation and evaluation of system solutions across multiple design responsibilities. Performing these simulations by hand can be onerous. Tools are readily available in the industry to assist the project team in maximizing their collaboration efforts.

This section discusses three critical, fundamental types of tools suggested for use in executing IDP. These are by no means the only tools available; an abundance of tools are available from government, utility, commercial, manufacturing, and technical society sources. Comprehensive listings of potential resources are available on the National Institute of Building Sciences (NIBS) Whole Building Design Guide Web site (http://www.wbdg.org/index.php).

Building Information Modeling

Building information modeling (BIM) is the process of using intelligent graphic and data modeling software to create optimized and integrated building design solutions. As such, it is an enabling tool for IBD (see Figure 2). The ultimate goal of BIM is to assemble a single database of fully integrated and interoperable information that can be used seamlessly and holistically by all members of the design and construction team, and ultimately by owners/operators throughout a facility's life cycle. The desired result is a BIM model where three-dimensional (3D) graphical imaging carries real-time (i.e., immediate and dynamic access) data, and where every line and every object carries real-life intelligent physical and performance data. That model includes the aesthetic, physical, and thermal properties of each component, as well as specification and cost data. The design team interfaces with the model to seamlessly generate comprehensive simulation evaluations, including natural daylight modeling, energy modeling, and life-cycle cost analysis of the building's integrated systems.

The modeling technology can start with direct data transfer from the design calculation software into graphic layouts (for systems such as structural steel, fire protection, or other modular elements). Alternatively, it can use the graphic layouts as direct input to load calculations (e.g., pipe sizing, duct sizing). Modeling programs can also link to specifications and to manufacturers' Web sites for data input. Either way, building information modeling technology already extends into fully integrated 4D modeling (adding the fourth dimension of time for scheduling or sequencing using programs) and 5D modeling (adding the fifth dimension of cost for estimating and budget control).

After design optimization is complete, the original modeling software can compile data from each discipline and generate a set of digital 2D or 3D construction documents for use in procuring construction bids. The model can interface with a contractor's cost estimating, scheduling, and project management software and manufacturers' material, fabrication, and cost databases to generate optimized cost estimates and construction schedules. The development can continue with the provision of automatic bills of material (BOM) and generation of automatic shop drawings for everything from structural steel to sheet metal duct fabrication, fire protection and piping fabrication, electrical cabling and bus duct layouts, etc. As construction progresses, the model can be continually updated to as-built conditions, including integration of manufacturers' installation,

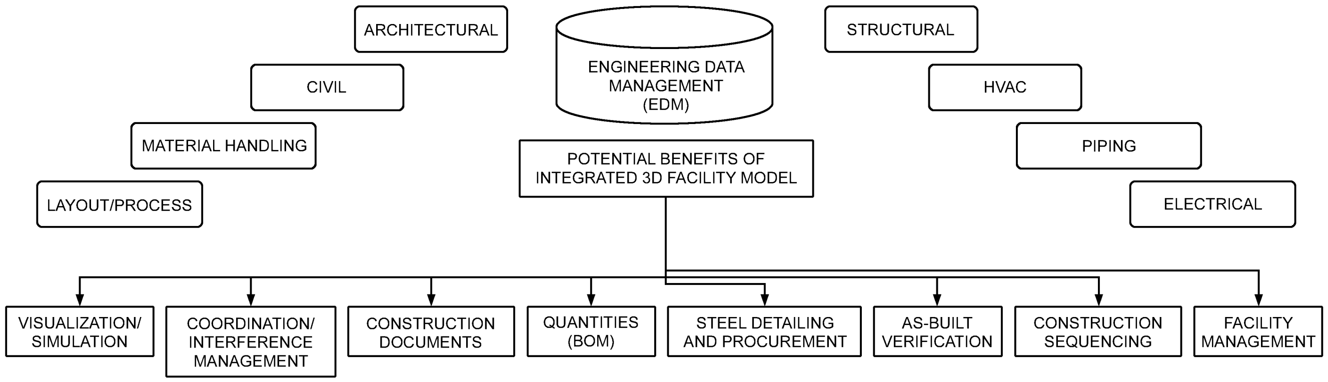

Fig. 2 Overview of BIM Benefits

operation, and maintenance data. This extends all the way through start-up and commissioning, and to facilities management with hyperlinks to operating and maintenance manuals, service contractors, and so forth.

There is a significant amount of work being done worldwide on software tool and protocol developments by governmental agencies, nonprofit and research organizations, as well as commercial entities, to facilitate and promote BIM technology. There is also significant new industry foundation class (IFC) compliant application software under development.

A major key to the success of these efforts is establishing common software protocols. The International Alliance for Interoperability (IAI), a council of NIBS, developed models to address this issue. IAI's Web site (http://www.iai-na.org/index.php) also provides information on programmable eXtensible Markup Language (XML) data models for information transfer between disparate software packages (e.g., aecXML is a framework for using an XML standard specifically related to technology in architecture, engineering, and construction). They also offer comprehensive, intelligent, and universal data models through IFCs to IFC.XML2 (ISO 10303-28), which incorporate HVAC schemas compatible with ifcXML/IFC2X3 code (ISO *Standard* 10303-11), as well as data elements that represent entire portions of a building or system. These are used to assemble computer-readable models of the facility that contain all of the information on the parts and their relationship (ISO/PAS-*Standard* 16739).

NIBS' Facility Information Council is developing a national building information model standard; NIBS' Building Enclosure Technology and Environment Council and the Facility Maintenance and Operations Council are also doing related work. NIBS is working with IAI to develop an overall integrated program developing and expanding IFC component values under the umbrella "buildingSMART," which combines BIM technology with information for the construction (IFC) global ISO standard. The first draft of the Standard is now available for review (IAI 2007).

Energy Modeling

Energy modeling uses scientific methods and analytical tools to estimate the energy consumption patterns of a given facility, constructed of given materials, located in a given climate zone, and operated according to given schedules. These tools and methods range from simple hand calculations and spreadsheets to the most sophisticated software packages designed to consider numerous building configurations, various zoning options, and multiple systems with many varied hours of operation. Some of the more common software tools include programs free for download such as the U.S. Department of Energy's (DOE) DOE2, Energy10, EnergyPlus, and eQuest. Commercial entities and equipment manufacturers also have products available to support building load calculation and detailed energy performance modeling.

Energy modeling should be used to help integrate and optimize a building's energy-consuming systems' performance over the facility's expected life cycle. Successful application of this tool comes from evaluating system solutions as early as possible to develop best-fit solutions for the developing design, thus minimizing radical design changes late in the design phases.

Energy modeling may also be used if it becomes necessary to value-engineer a project after the design phase is complete. Simple substitutions of less costly materials, products, equipment, or systems during the value-engineering stage of a highly integrated building design may have serious and profound negative effects on the building's future energy and environmental performance if not properly analyzed before acceptance.

Energy models should only be developed by team members who have extensive experience in the creation of such models and who truly understand the dynamics of building operations. Energy modeling is a tool used to estimate the energy performance of a building and its systems for comparison to other alternatives performing under similar conditions and constraints at a given time, and is used for informed and intelligent decision-making purposes. Weather patterns change; plug loads and technology use change; users' preference for thermostat set points often differ from those modeled; material properties change and degrade over time; system and equipment maintenance may be kept current or deferred after owner occupancy; and hours of usage and operation change; these are just a few reasons why modeled energy use rarely tracks favorably with actual usage patterns. The following points should always be kept in mind when using energy models for system evaluation:

- Model results are not a guarantee of actual or future performance
- Model results are not a guarantee of actual or future energy costs

Refer to Chapter 32 in the 2005 *ASHRAE Handbook—Fundamentals* for an in-depth discussion on modeling methods for systems design and design optimization.

Life-Cycle Analysis Tools

All system evaluations share a common need to demonstrate what the financial effects are relative to total ownership cost. This requires a comprehensive comparison of capital, utility, energy, maintenance, replacement, disposal, and occupant costs for the facility's projected life. Life-cycle cost analysis (LCCA) provides a means of examining how each of these factors impact the owner's cost obligations.

A comprehensive methodology for facilitating life-cycle comparisons can be found in the National Institute of Standards and Technology's *Handbook* 135, Life-Cycle Costing Manual for the Federal Energy Management Program (NIST 1996). NIST provides a number of supplemental publications and tools that should be used in conjunction with this source, including the following:

- Annual supplements to *Handbook* 135, providing annually updated energy price indices and discount factor multipliers
- The DOE's Building Life-Cycle Cost (BLLC) Computer Program, which provides an electronic means of applying the methodology of *Handbook* 135

All of NIST's life-cycle publications, tools, and annual updates may be downloaded from the U.S. Department of Energy's Federal Energy Management Program Web site.

Chapter 36 in the 2003 *ASHRAE Handbook—HVAC Applications* contains expanded LCCA reference material that focuses on direct HVAC system and component effects, as well as valuable perspectives and data on owning, operating, and maintenance cost factors.

CLIENT PROCESS

Project inception begins with the owner and a need to begin construction of a facility. Successful incorporation of IBD objectives is set at this point, before execution of the first design calculation.

Programming

When a need for facility space is created, the owner must first evaluate options available to meet the required facility need. The scenarios of construction, reduced construction, or no construction should be debated to determine which option provides the best-fit alternative. Questions to consider include the following:

- Are adaptive reuse alternatives available?
- Does the program need have redundancies that contribute to wasteful infrastructure construction?
- Can operating schedules be adjusted to minimize built space?
- Do consolidation opportunities exist within and outside the organization that could foster more environmentally responsive built solutions?

- Do multiple use opportunities exist that can support additional program uses, expanded use potential, and operational scalability?
- What are the real and artificially generated work sequence needs? Accelerated project delivery may be required, but such action may not allow for optimized solutions to be thoroughly developed and evaluated.
- What are the project objectives as seen from the owner's perspective? Early definition of objectives is instrumental in assembling the correct project team members.
- Based on definition of the project objectives, who will best serve the role as IBD champion for the owner's interest?

Siting

The location of the proposed built facility directly influences the course the IDP takes. Site alternatives need to be researched to determine whether site contamination may influence infrastructure solutions, or whether wetland offset measures need to be implemented at other sites.

The location and suitability of utility resources must be identified. Sites should be selected that allow options and flexibility when system solutions are being considered. Lack of available utilities affects optimization models. Basic features to consider include the following:

- Is potable water available from a municipal source, or will well water be required? If provided from a municipal source, what line pressures are available?
- Is a municipal sanitary sewer available, or will an on-site septic system be required?
- What is the proximity of electricity, gas, and district energy systems?
- Is the site conducive to implementation of renewable site/source energy?

Neighbor relations present another decision matrix for the owner to consider. The proposed location of a built facility and the specific operational dynamics may contribute negatively to the surrounding community. Questions to ask that may lead to unique project mitigation objectives include the following:

- What will the effects on traffic be for building occupants and neighboring communities?
- Do operational usage schedules complement neighboring communities?
- Will light-trespass mitigation and ambient-noise abatement be required?

Budgeting

Once the owner's program is set, siting options have been evaluated, and mitigation needs have been defined, the owner needs to appropriate funding to support design, construction, and operation of the facility. Funding sources should be planned to cover anticipated professional services fees, capital construction costs, contingencies, escalation costs, maintenance costs, utility/energy costs, and occupant costs. Allocations should be made with an eye towards encouraging collaborative optimization efforts and leveraging noncapital costs to minimize overall total ownership cost.

Team Selection

Design team members should have a high degree of competence and knowledge gained though education and experience on similar projects. When team selection occurs can vary, depending on the client's in-house capabilities. Typically, the design team needs to assist the owner during initial programming and siting activities. Regardless of the timing, it is imperative that the team be selected based on qualifications that support the project objectives.

COLLABORATION

Collaborative design requires that all members of the design team possess demonstrated expertise, an ability to work collectively in a nonisolated setting, and a drive of stewardship to support the IDP vision. Team members should share similar corporate philosophies, have compatible operating procedures, use common optimization tools, and be committed to adhering to consistent interdisciplinary quality assurance/quality control (QA/QC) procedures.

Teamwork

Working with a team requires that participants engage in joint decision making. Individual thinking and processes must give way to support the team and a decision-making mentality that supports the direction of the team. Individuals must keep in mind that their actions and reactions affect integrated system solutions. Design in isolation does not support team collaboration.

Team members must foster a professional level of respect for each other. When individuals suggest new strategies to improve the whole, dissident views will occur. Emotions must be removed from these events. Evaluations must be made on objective application and support of meeting project objectives.

The project team leader should be trained to handle conflict management and dissident views in a professional manner. Consensus agreement will not always be apparent, and the project team must avoid fracture of the collaborative effort when differences occur.

Effective, concise, and complete communication must be adopted to keep the team informed of all decisions across all design disciplines. Communications within the project team should be standardized as much as possible. Each form of communication should contain the date the communication originated, any revision dates, project name, project number, and the originator's contact information. In addition, a clear and concise subject line should be included to focus recipients to the subject matter at hand. For collaboration to work, all team members must be kept in the communication loop so that each understands where the collaboration process stands.

Team Formation

The importance of experience in an integrated design team cannot be stressed enough. Systems thinking requires input from individuals who have extensive design experience and understand how systems and components interact. IDP cannot succeed when key representatives are cast into on-the-job training. On the other hand, IDP provides an excellent opportunity to mentor and train supporting staff in system integration, and the opportunity should be fully exploited.

Participation in IDP requires individuals to have a proactive attitude that supports the ups and downs of iterative system evaluation. Individuals who can see the big picture and appreciate that the whole will be better than the sum of the parts enhance the team efforts.

Participants should have experience with optimization techniques. This equates to more than being able to run a load calculation. True optimization expertise requires understanding how building systems interact, what elements can be examined for the benefit of the whole, and how to evaluate results in detailed financial models that consider all ownership costs.

Some projects may require adding specialty consultants to the project team to support activities such as smoke control, acoustics, seismic restraint, or food service. Rarely do all expertise needs reside within the same firm on complex projects. Managing outside specialty consultants is an added responsibility that must be factored into the collaborative process.

As with the owner, the design team requires an IBD champion to keep focus on the project objectives.

Decision-Making Criteria

As system evaluations are made, benchmarks or baselines must be established to measure the suitability of system evolution. These decision-making criteria must be agreed to with the owner before any design work begins. Criteria need to be realistic, allow for maintaining pace with the budget limitations, accommodate strategic flexibility, and address budget correction possibilities when the need arises. The basis of the criteria depends totally on the owner's resource capabilities and financial position, but in all cases should be based on meaningful life-cycle analysis.

Scenarios may arise that challenge the design criteria and defined objectives for the project. It is not uncommon for project scopes or financial factors to change during project design, procurement, or construction. This deviation from the original path may require a reprioritization of objectives and a change in the decision-making criteria. The team should be prepared to adapt to such dynamics and be able to refocus the IDP in a responsive and efficient manner.

Strategy Development

To proceed with the IDP, proposed strategies should lead the team toward a built facility of integrated systems. Development of these strategies is influenced by the prioritization of project objectives and by the direction of the developing building solution. Using the simple, but not quantified, objective of reduced energy use as an example, the following broad strategies and substrategies reflect the progressive optimization for a commercial office building in the southeastern United States. Note that the example does not provide an all-inclusive strategy roadmap, or represent a fixed recommendation.

1. Minimize building envelope load
   - Optimize siting and footprint aspect ratio to maximize east/west orientation
   - Incorporate effects of major sky obstructions such as buildings, trees, and geological features
   - Minimize east/west-facing glass
   - Incorporate overhangs to reduce solar radiation component during warm months
   - Optimize glass thermal quality and solar transmittance capacity per orientation
   - Optimize roof thermal and solar reflectance performance
   - Optimize wall and floor thermal performance
2. Minimize building performance load effects
   - Incorporate daylighting to improve visual comfort and to reduce connected ambient light load
     - Modify glass to control solar radiation, but allow visible light transmittance
     - Adjust initial space layout to provide open areas on building perimeter
   - Incorporate passive solar reclaim on south exposure to offset winter heating load
   - Incorporate green roof systems to stabilize year-round plenum temperature
3. Minimize connected internal load
   - Identify a realistic occupant use schedule and integrate with internal load components
   - Optimize applied lighting efficiency and staging controls
   - Maximize efficiency of office equipment
4. Develop HVAC infrastructure based on optimized load profile (for simplicity, other MEP infrastructure system dependencies are excluded from the primary demonstration)
   - Select best-fit strategy for HVAC systems based on minimized building load, use profile, and ventilation requirements. Note that this exercise requires extensive modeling by the HVAC engineer to find the best-fit solution. (For this example, assume that a water-cooled chilled-water plant, hot-water gas boiler plant, gas-fired desiccant dedicated outside air unit, and four-pipe fan-coil terminal units have been shown to provide the best-fit energy performance solution that maintains budget control. There is no basis to this selection other than to demonstrate subsequent evaluation strategies.)
5. Optimize HVAC systems
   - *Chiller plant*
     - Analyze terminal unit cooling coil selections to determine water temperature differential needed to provide cooling performance, minimize distribution pipe size, and minimize pumping capacity
       - Optimize condenser water temperature differential to find best fit for chiller, cooling tower, and condenser water pumps
       - Evaluate effect of water-side economizers
       - Evaluate application of condenser water heat recovery as a waste heat source
   - *Boiler plant*
     - Analyze terminal unit heating coil selections to determine water temperature differential needed to provide heating performance, minimize distribution pipe size, and minimize pumping capacity
   - *Ventilation system*
     - Analyze effect of energy recovery on dedicated outside air unit and central plant capacities
     - Evaluate distribution options and effect on air horsepower for delivery of ventilation air to the occupied space
6. Optimize HVAC components
   - *Chiller plant*
     - Optimize chiller for best-fit performance compared to projected load profile and condenser water relief opportunities
     - Optimize cooling-tower performance using air or water modulation compared to projected load profile
     - Examine effect of motor efficiency improvements on pumping systems
     - Optimize sizing of noncritical path piping mains and branches
   - *Boiler plant*
     - Optimize boiler performance compared to projected load profile
     - Examine effect of motor efficiency improvements on pumping systems
     - Optimize sizing of noncritical path piping mains and branches
   - *Ventilation system*
     - Examine effect of motor efficiency improvements on fan systems
     - Optimize sizing of noncritical path duct mains and branches

This simple example demonstrates that there are many possible strategies for a project. The magnitude is greatly expanded when multiple objectives are pursued. In the example, note that HVAC system design is not even a factor until development of the least-load-impact building is assembled. Only then do applied MEP system solutions come into focus. The example strategy development supports the object: reduce energy use by minimizing load, right-sizing systems to meet the load, and then maximizing component efficiency to match the use profile.

Iterative Evaluation and Analysis

As the example strategy for minimizing energy use demonstrates, there are multiple development steps that must be followed in pursuit of IBD objectives. Design of the final product depends on looking at each system-level component contribution and determining whether incorporation of the proposed strategy improves the project whole within the guidelines of the decision criteria.

As each strategy is explored, numerous *what-if* questions must be evaluated and accepted or discarded. Acceptance allows the team to move forward, but does not preclude returning for reevaluation later. Nonacceptance may progress into alternative solutions for the target strategy, or it may lead to totally discarding the strategy and moving forward. Discarding a strategy does not preclude returning to it later.

Obviously, IDP requires significant effort and creativity to (1) develop applicable strategies to meet project objectives, (2) refine strategy flow as the building evolves, (3) define component variables as each strategy is evaluated, (4) analyze the financial effects of each strategy, and (5) repeat the process over many iterations.

DESIGN ACTIVITIES AND DELIVERABLES

Some of the more common design activities and deliverables are affected by IDP. Some schools of thought suggest that these items be decoupled from integrated practice, but this perspective unfortunately misses the underlying premise that all activities in the project delivery process have a certain level of interdependency. When collaborative design strategies are used, these interdependencies require increased stewardship.

Drawings

The drawings are graphic representations of the work on a project, and include plans, elevations, sections, details, legends, notes, abbreviations, and schedules. They are often diagrammatic, and rarely show every detail required to construct a facility. Drawings show quantities, extents, and spatial relationships of the elements of construction to each other and existing conditions and surroundings. They may identify a particular product, material, finish, or process many times. However, the particular product, material, or process should be specified only one time in the specifications. Descriptions and identifiers on the drawings should be simple, concise, and generic. IBD does not change this basic definition.

IBD does have an effect when it comes time to communicate the system solutions onto drawings that will be used for construction. Coordination now becomes an appropriate and critical IDP tool. The project team must take time to ensure that the integrated work results are correctly identified throughout the drawing set.

The project team should avoid issuing drawings in decoupled groups or individual sheets during the procurement phase. Bidding in isolation is just as detrimental as design in isolation when it comes to achieving integrated solutions.

Specifications

The project manual is the textual description of the work and other requirements for a project; it includes procurement and contracting requirements, general requirements, and technical specifications for the work of the project.

Specifications describe the administration, quality, products, materials, workmanship, warranty, testing, and start-up requirements of the work of a project (CSI 2005). For uniformity in structure, location of information, consistency, and quality control, it is best if the specifications are organized into divisions and subdivisions (sections) that correspond to the major divisions of work required to complete the project as defined in *MasterFormat* (CSI 2004).

The 2004 edition of *MasterFormat* includes some very powerful new sections to assist in IBD delivery, including the following level 2 and 3 additions to division 01, General Requirements:

- 01 33 00, Submittal Procedures
  - 01 33 29, Sustainable Design Reporting
- 01 78 00, Closeout Submittals
  - 01 78 53, Sustainable Design Closeout Documentation
- 01 81 00, Facility Performance Requirements
  - 01 81 13, Sustainable Design Requirements
  - 01 81 16, Facility Environmental Requirements
  - 01 81 19, Indoor Air Quality Requirements
- 01 86 00, Facility Services Performance Requirements
  - 01 86 19, HVAC Performance Requirements
  - 01 81 23, Integrated Automation Requirements
- 01 91 00, Commissioning
  - 01 91 13, General Commissioning Requirements
- 01 92 00, Facility Operation
  - 01 92 13, Facility Operation Procedures
- 01 93 00, Facility Maintenance
  - 01 91 13, Facility Maintenance Procedures

Tools are in place in the industry to support communication of integrated system design into work results that can be consistently located. Further study of the *MasterFormat* structure will demonstrate that individual facility services, such as HVAC, have defined specification structures to support effective communication of system solutions.

Value Engineering

Value engineering (VE) is similar to life-cycle cost analysis, and may be performed at any phase of design. It is most often performed when potential construction cost overruns have been identified, or alternative systems or substitute equipment is being considered. Applying the same methods described for life-cycle cost analysis, the alternative system or component being value engineered should be analyzed for its total ownership cost effect. The results should then be compared to the project objectives to see if incorporation has merit.

When VE is complete, recommendations should be made to the owner describing the process and methods used to determine the total cost of the system(s) analyzed. The system that best suits the owner's needs and expectations should be indicated. Recommendation of proposed VE alternatives should indicate how the defined project objectives are affected.

Risk Management

Risk management includes the following:

- Systematic, consistent application of written standard office procedures
- Judicious implementation of QA/QC procedures
- Comprehensive record keeping
- Timely and accurate communications
- Written contracts that include certain basic terms and conditions for all services rendered

Because IDP involves significant collaboration, team members need to practice a policy of keeping good, complete, contemporaneous records of the facts discussed and decisions made (and by whom) in meetings, during site visits, in e-mails, and during telephone conversations. Most errors and omissions (E&O) and liability insurance carriers and their legal counsels offer guidance, and customarily provide publications on risk management as part of their service to their insured. Team members should be well versed in how to practice proactive risk management so that liability paralysis does not reduce collaborative participation.

Budget Control

Traditionally, there are two types of budgets the design team must manage during the design phase: design cost and construction cost. Note that this is not an absolute, because there could be a deviation if progressive-thinking owners incorporate all or portions of operating-related budgets into the equation.

Design cost control begins with design team resource allocation, budgeting, and scheduling while preparing the fee proposal. Once a complete scope of work has been defined, a project budget analysis should be prepared and submitted with the fee proposal to the client. In the SDP model, regular monitoring of actual design cost as compared to the original project budget analysis and scope of work should help avoid scope creep and ensure that projects are delivered within the design fee budget. The IDP model requires that design fee budget control include an additional oversight element. Although infinite evaluations may lead to the absolute best built solution, design fee structures have a practical limit on how many evaluations are affordable. It is therefore financially critical for the design professional to develop a clear strategy at the time of fee negotiation so that all parties agree on the extent and quantity of strategy evaluations, how the fee is structured to reflect the applied effort at the time of service, and how additional services are accommodated if additional evaluations are required.

Responsible control of construction cost budgets can vary depending on the project delivery model. Design-bid-build models place the design team in an oversight role. Design-build allows the contracting entity to control cost of the delivered solution. Design-CM brings in a third-party construction manager, who is responsible for delivery of the project within the defined construction budget. IBD is achievable under any of these delivery models. Each requires, however, accurate cost projections to support realistic system evaluation. Likewise, the construction budget needs to represent a level of funding that supports construction of the final system solutions. Cost projection and cost control play hand-in-hand throughout the iterative evaluation process.

Constructability Review

Constructability is a measure of how well construction documents provide the construction team with the information necessary to complete and deliver a project that meets the owner's expectations and documented project requirements. A constructability review is an organized process of reviewing construction documents during the design phases to make recommendations to the owner and design team about how the design may better define expected construction work results. The IDP is well served when knowledgeable construction representatives provide objective feedback on the constructability of developing system solutions.

Operational Review

Operational reviews should be conducted during the design development and construction document phases of design. Depending on the owner, this type of review may be increased to correspond with evaluation scenarios. Operational review can also be one of the decision-making criteria used on a project.

Reviewers should be knowledgeable about systems, equipment, controls, operation, and maintenance. Ideally, the review should include representation from the group that will be ultimately responsible for operating the facility. During the review, sequences of operation should be thoroughly reviewed to ensure that integrated solutions are truly integrated. Equipment location should be reviewed to verify that required maintenance clearance and accessibility are provided. Drawings and specifications should be checked to ensure that (1) the appropriate level of system and component commissioning has been prescribed, (2) adequate and usable close-out documentation has been itemized, and (3) sufficient training has been scheduled for operational staff.

Operational constraints must be considered when system solutions are developed. Nonconventional systems and equipment can be somewhat intimidating for building operators. The issues of perceived complexity and risk must be mitigated. Solutions must be kept in perspective with the client's ability to operate and maintain the facility. Operational review is an excellent process to address these concerns.

Commissioning

Commissioning is a systematic process of applying QA/QC procedures to the design and construction of a building, to verify that key elements of the design are, in fact, constructed as designed, and started, tested, operated, and maintained so that the building meets the designer's intent and owner's expectations.

ASHRAE defines commissioning of HVAC systems as "the process of ensuring that systems are designed, installed, functionally tested, and capable of being operated and maintained to perform in conformity with the design intent. Commissioning begins with planning and includes design, construction, start-up, acceptance and training, and can be applied throughout the life of the building" (ASHRAE *Guideline* 1).

Commissioning is a rigorous and intense process that should be used when integrated-system-based design solutions are provided. See Chapter 42 for more information.

PROJECT DELIVERY SEQUENCE FOCUS

IDP applies to all phases of project delivery, not just the standard design phases. Successful delivery requires that the entire project team contribute to their role at the appropriate time. The project team should be cognizant of the unique effort focus required within each phase. The following outline identifies key focus elements that IDP should consider:

- Owner planning
  - Determine best-fit construction need
  - Identify least-impact, best-fit siting option
  - Define project objectives
  - Structure project delivery budget to support IDP delivery
  - Select team to support project objectives
- Predesign
  - Refine project objectives
  - Define decision-making criteria
  - Develop strategies to support project objectives
  - Develop initial program solution
- Schematic design
  - Develop facility solution assembly
  - Optimize facility systems
  - Apply facility services solutions to support optimized facility
- Design development
  - Optimize all facility and services systems
- Construction documents
  - Optimize all facility and services components
  - Communicate system solution accomplishments into constructable work results
- Procurement
  - Provide oversight to ensure that procurement document revisions do not negatively affect developed system solutions
  - Adjust project objectives and conduct new strategy evaluations as required to respond to dynamic scope modifications
- Construction
  - Adjust project objectives and conduct new strategy evaluations as required to respond to dynamic scope modifications
  - Provide oversight to ensure that product substitutions and contract document revisions do not negatively affect developed system solutions
  - Provide oversight of facility and services construction to ensure that work results comply with design intent
- Operation
  - Verify that systems and components operate as intended across all seasonal and usage conditions
  - Verify that operational staff fully understand how systems work holistically
  - Verify that applicable maintenance procedures and plans are understood to support systems and components for the facility life cycle.

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RESOURCES

BLLC	www1.eere.energy.gov/femp/information/download_bllc.html
DOE2 and Energy10	www.eere.energy.gov/buildings/highperformance/simulation_software.html
EnergyPlus	www.eere.energy.gov/buildings/energyplus/
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