

CHAPTER 58

INTEGRATED BUILDING DESIGN

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INTEGRATED building design (IBD) promotes holistic collaboration by project team members during all phases of project delivery. It emphasizes optimizing system solutions based on the project's objectives, in the context of whole-building performance. Optimizing system solutions requires the participation of all team members. For IBD to succeed and be beneficial, the entire project delivery team must be committed to, understand, and remain engaged in the process, from setting the owner's program requirements through the completion of construction, commissioning, handover and start-up, and operations and facility management.

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. **Table 1** outlines the basic framework and major milestones, listing the questions that must be answered by team members as they complete one phase of work and seek approval to move forward to the next phase.

This table lists the tasks comprised by integrated building design project. It is intended to provide guidance to a project team, and must be adapted to each specific project. It breaks down a typical building project into phases, and in each phase is a list of go/no-go questions to be answered *yes* or *no* by the owner. If all questions are answered *yes*, then the decision is to go forward and begin work in the next phase. If any question is answered *no*, then the decision is no-go: this does not stop the project, but continues the team's work in the current phase until all answers are *yes*. The owner should require a *yes* answer to every question in a phase before approving work to begin in the next phase, because each phase builds on those before it. If a phase is not done well, then those that follow are at higher risk of producing an inferior project.

All decisions described in **Table 1** are made by a cross-functional team. The makeup of this team varies by project and by phase. At a minimum, the team includes those responsible for designing, building, operating, and maintaining the facility's systems.

Typically, teams make decisions by consensus. That means that all share the responsibility for decisions, and provide their expertise to the decision at hand. Project integration specialists are valuable in this process: their expertise is leading the team, ensuring that all decisions are made by teamwide consensus, and emphasizing compromises that accommodate valid concerns affecting other disciplines. Project integration specialists have a strong technical understanding of how building systems work together, and their skills include cross-functional team leadership, consensus decision management, and capitalizing on the expertise of all members.

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.

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

1. OWNER PROCESS

A project begins when an owner wants to satisfy an unmet need. Successful incorporation of IBD objectives is set at this point, before design begins.

Programming

When new facility space is required, the owner must first evaluate options available: build new, modify existing, or relocate. These scenarios should be debated to determine which option provides the best-fit alternative. Questions to consider include the following:

- Are adaptive reuse alternatives suitable in the project and available?
- Does the program have redundancies that contribute to wasteful infrastructure construction?
- Can operating schedules be adjusted to minimize built space?
- Are there consolidation opportunities in and outside the organization that could foster more environmentally responsive built solutions?
- Are there multiple-use opportunities that can support additional program uses, expanded use potential, and operational scalability?
- If accelerated project delivery is required, what are the consequences for not thoroughly developing and evaluating optimized solutions?
- What does the owner feel are the project objectives? 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 proposed building's location directly influences the course the IBD takes. Site alternatives need to be researched to determine whether site contamination may influence infrastructure solutions, or whether wetland offset measures must be implemented at other sites.

The location and suitability of utility resources must be identified. Sites should allow options and flexibility, because lack of available utilities affects optimization models. Basic features to consider include the following:

- Is potable city water available, 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?
- Is a city stormwater system available? If not, what are the alternatives for handling stormwater runoff?
- How close are electricity, gas, and/or district energy systems?
- Is the site conducive to implementation of renewable site/source energy?

Table 1 Integrated Building Design Checklist

Go/No-Go Question	No	Yes	Go/No-Go Question	No	Yes
Phase 1: Market Justification			Phase 5: Construction Preparation		
Has the market justification assessment been completed by a team of highly skilled people, assigned by the owner?	<input type="checkbox"/>	<input type="checkbox"/>	Is the project price agreed between the owner and contractor(s)?	<input type="checkbox"/>	<input type="checkbox"/>
Has the team identified and clearly defined a need for this built space?	<input type="checkbox"/>	<input type="checkbox"/>	Do the construction documents include answers to all bid questions and scope of work change agreements?	<input type="checkbox"/>	<input type="checkbox"/>
Has the team prepared a plan to complete Phase 2, including key team members, objectives, funding required, and schedule?	<input type="checkbox"/>	<input type="checkbox"/>	Do the construction documents include all cost reduction design changes and related OPR changes?	<input type="checkbox"/>	<input type="checkbox"/>
Has the team demonstrated financial justification and funding available to complete Phase 2?	<input type="checkbox"/>	<input type="checkbox"/>	Does the team agree that commissioning work completed in accordance with construction documents will prove that building performance meets the OPR?	<input type="checkbox"/>	<input type="checkbox"/>
Phase 2: Project Initiation			Are contractors prepared to perform the commissioning tests and inspections required by construction documents?	<input type="checkbox"/>	<input type="checkbox"/>
Is there a commitment to high performance?	<input type="checkbox"/>	<input type="checkbox"/>	Are the means and methods for project communication and decision making clearly defined?	<input type="checkbox"/>	<input type="checkbox"/>
Is integrated building design or integrated project delivery justified?	<input type="checkbox"/>	<input type="checkbox"/>	Has the team prepared a plan to complete Phase 6, including key team members, objectives, funding required, and schedule?	<input type="checkbox"/>	<input type="checkbox"/>
Have the owner's operation and maintenance (O&M) capabilities been documented?	<input type="checkbox"/>	<input type="checkbox"/>	Phase 6: Construction		
Does the owner's O&M staff possess expertise that could contribute to successful outcome of the project?	<input type="checkbox"/>	<input type="checkbox"/>	Are all systems built and equipment installed in accordance with the construction documents and certified as such in accordance with commissioning requirements?	<input type="checkbox"/>	<input type="checkbox"/>
Have these members been identified and included in the owner's team?	<input type="checkbox"/>	<input type="checkbox"/>	Has the owner's facility management/maintenance staff made regular visits during construction to ensure maintainability of installed equipment?	<input type="checkbox"/>	<input type="checkbox"/>
Has the commissioning agent prepared the first draft of the owner's project requirements (OPR)?	<input type="checkbox"/>	<input type="checkbox"/>	Are all systems and equipment operating as intended and certified as such in accordance with commissioning requirements?	<input type="checkbox"/>	<input type="checkbox"/>
Has the project initiation team defined attributes of the concept development and design phases cross-functional team members?	<input type="checkbox"/>	<input type="checkbox"/>	Has the authority having jurisdiction (AHJ) approved the project for occupancy and agreed that all required inspections and tests are complete and satisfactory?	<input type="checkbox"/>	<input type="checkbox"/>
Have members of the concept development and design phases cross-functional team been recruited?	<input type="checkbox"/>	<input type="checkbox"/>	Is the owner O&M training plan complete?	<input type="checkbox"/>	<input type="checkbox"/>
Has a project integration specialist been recruited to join the team?	<input type="checkbox"/>	<input type="checkbox"/>	Has the team prepared a plan to complete Phase 7, including key team members, objectives, funding required, and schedule?	<input type="checkbox"/>	<input type="checkbox"/>
Has the team prepared a plan to complete Phase 3, including key team members, objectives, funding required, and schedule?	<input type="checkbox"/>	<input type="checkbox"/>	Phase 7: Owner Acceptance		
Has the project initiation team demonstrated that there is financial justification and funding available to complete Phase 3?	<input type="checkbox"/>	<input type="checkbox"/>	Are all systems operating in accordance with the OPR?	<input type="checkbox"/>	<input type="checkbox"/>
Phase 3: Concept Development			Does the owner have all documentation required to operate and maintain the building?	<input type="checkbox"/>	<input type="checkbox"/>
Is the OPR complete, documenting clear and measurable targets for building performance, suitable for monitoring building operating performance?	<input type="checkbox"/>	<input type="checkbox"/>	Have all required documents and maintenance procedures been incorporated in the owner's maintenance management system?	<input type="checkbox"/>	<input type="checkbox"/>
Has the team agreed on one set of systems concepts that define the whole building?	<input type="checkbox"/>	<input type="checkbox"/>	Have the owner's O&M people been trained in the proper operation and maintenance of the integrated whole-building systems?	<input type="checkbox"/>	<input type="checkbox"/>
Have the attributes of specialty resources been defined and are they available as needed?	<input type="checkbox"/>	<input type="checkbox"/>	Is the owner prepared to operate and maintain building performance in accordance with the OPR?	<input type="checkbox"/>	<input type="checkbox"/>
Has the team prepared a plan to complete Phase 4, including key team members, objectives, funding required, and schedule?	<input type="checkbox"/>	<input type="checkbox"/>	Has the team prepared a plan to monitor the performance of building systems throughout the warranty period and tune or repair systems as necessary to make the building perform as required by the OPR?	<input type="checkbox"/>	<input type="checkbox"/>
Has the project initiation team demonstrated that there is financial justification and funding available to complete Phase 4?	<input type="checkbox"/>	<input type="checkbox"/>	Phase 8: Use, Operation, and Maintenance		
Phase 4: Design			Does operating performance under normal use and occupancy meet the OPR?	<input type="checkbox"/>	<input type="checkbox"/>
Has the integrated team, including design professionals, construction contractors, and owner's O&M staff, worked together to perform design work?	<input type="checkbox"/>	<input type="checkbox"/>	Are O&M personnel in place and prepared for ongoing operation?	<input type="checkbox"/>	<input type="checkbox"/>
Are schematic design documents complete and delivered to owner?	<input type="checkbox"/>	<input type="checkbox"/>	Do all team members agree that the project is complete?	<input type="checkbox"/>	<input type="checkbox"/>
Are design development documents complete to the extent necessary for pricing and delivered to the owner?	<input type="checkbox"/>	<input type="checkbox"/>			
Has the team prepared a plan to complete Phase 5, including key team members, objectives, funding required, and schedule?	<input type="checkbox"/>	<input type="checkbox"/>			
Has the design team demonstrated that there is financial justification and funding available to complete Phase 5?	<input type="checkbox"/>	<input type="checkbox"/>			

Transportation conditions must also be identified, such as whether local and regional road systems are

- Suitable for moving raw materials in and transporting processed products out
- Sufficient for transporting materials and products consistently

Neighbor relations present another decision matrix for the owner to consider. A facility's location and specific functions may contribute negatively to the surrounding community. Questions that may lead to unique project mitigation objectives include

- What will the effects on traffic be for building occupants and neighboring communities?
- Do operational use schedules complement those of neighboring communities?
- Will abatement of light trespass and ambient noise be required?
- How will stormwater runoff affect adjacent properties?

Budgeting

The next step is for the owner to appropriate funding for design, construction, and operation of the facility. Funding sources should be planned to cover anticipated professional services, capital construction, contingencies, escalation, maintenance, utility/energy, and occupant costs. Encourage collaboration to optimize expenses and leverage noncapital costs to minimize overall total ownership cost.

Occasional budget shortfalls are not uncommon. Early in the process, incorporate a reasonable contingency (~10 to 20%) into the budget to allow for unknowns and minor changes as the project evolves.

Team Selection

Design team members should be highly competent, knowledgeable, and experienced on similar projects. Team selection can vary, depending on the client's in-house capabilities, but typically, members need to assist the owner during programming and siting. Team members' qualifications must support the project's objectives.

2. OBJECTIVES

Project objectives 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 lead to practical, constructable results. This section outlines typical objectives; consult application-specific materials for effects and detailed descriptions.

Various sustainable, green, and high-performance prescriptive point systems are available to promote particular delivery objectives (e.g., sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality). Although these objectives are highly desirable and promote responsible environmental stewardship, meeting the defined project objectives is of primary importance, not accumulating points in a prescriptive rating system.

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 must be tailored to each project. 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, and many variations, combinations, and themes are possible. The project's underlying objectives should be fulfilled before accumulating performance-rating-system points 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 attention for certain facilities or sites. Theaters, for example, have specific noise criteria necessary for proper operation. Meeting these criteria for specific buildings 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 be critical. The project team must clearly understand the individual facility's thermal conditions and range of acceptable variation. This criterion significantly affects the size, type, and complexity of potential infrastructure solutions.

Depending on the climate and operational needs, **humidity or moisture control** may be appropriate. 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. 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.

Light quality can be a concern for some 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 energy consumption by decreasing the need for artificial indoor lighting systems.

Water Usage

IBD objectives for water usage typically focus on conservation and reclamation efforts. Water has a cost associated with its use, and should be modeled in the total ownership cost of a facility.

Water conservation and reclamation do not apply only to plumbing: 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 used in a host of facility service applications, such as cooling tower makeup, landscape irrigation, urinal flushing, etc.
- Capture all facility stormwater 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 limit water consumption. This, of course, must be balanced against the suitability of an integrated maintenance program and limited to local water quality characteristics

that do not contribute to scale, corrosion, fouling, and microbial growth.

Vulnerability

Global events and operational needs may dictate addressing building vulnerability. The facility infrastructure may require protection from seismic incidents, explosive blasts, or chemical and biological contamination. Indoor operations that create explosion, chemical, biological, or radiological hazards may also require attention. Additionally, protecting occupants in the facility may be an inclusive or stand-alone 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 59](#) for more information.

Environmental Stewardship

Waste reduction is a pressing need in the built world. The capacity of landfills to absorb construction debris is not limitless, and reuse and recycling can help mitigate landfill overuse. 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 climate change 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

Some 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 elements 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.

3. 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 IBD. 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 team's direction. 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 origination date, any revision dates, project name, project number, and originator's contact information. In addition, a clear and concise subject line should be included to focus recipients on 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 an experienced, integrated design leader cannot be overstressed. Systems thinking requires input from individuals who have design experience to match the project at hand. Decisions must be based on understanding how systems and components interact. The integration leader must ensure that those with limited cross-functional experience listen to other viewpoints and adapt their work for the best whole-building solutions.

IBD can succeed when key representatives learn as they go, but the work may take longer and require more iterations as the new participants are trained in the system. IBD provides an excellent opportunity to mentor and train supporting staff in system integration, and the opportunity should be fully exploited.

Participation in IBD 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's 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. Only rarely can one firm meet all necessary needs on complex projects. Managing outside specialty consultants is an added responsibility that must be factored into the collaborative process.

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

Decision-Making Criteria

Benchmarks or baselines must be established to evaluate how well the evolving system matches the project needs. 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 criteria depend 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. Project scopes or financial factors often 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 IBD responsively and efficiently.

Strategy Development

IBD strategies should lead the team toward the desired end result: 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 unquantified 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
 - Optimize fenestration and door orientations for best whole-building energy consumption
 - 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 mechanical, electrical, and plumbing (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, arbitrarily assume that a water-cooled chilled-water plant, hot-water gas boiler plant, gas-fired desiccant dedicated outdoor

air unit, and four-pipe fan-coil terminal units have been shown to provide the best-fit energy performance solution that maintains budget control.)

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 power 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 completed. 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.

Interdisciplinary Integration

Coordinate with other disciplines to optimize the design arrangement inside the building to shorten construction duration, reduce overall project cost, and enhance convenience for interdisciplinary operation and maintenance.

The entire building project should be considered as an integrated system, with a unified overall scope of work and unified timeline schedule to be performed and achieved by an integrated design and construction team. In this integrated system, all individual systems

and their components should be considered as subsystems of the overall integrated building project. Subsystems in a complete project include the following:

- Overall site plan; entrances and gates; roads and transportation; landscape; electrical substations or electrical main connection; gas or other fuel main intake pressure regulation station; water, sewer, sanitary, and storm drain piping and main connections; telephone, network, security, and fire protection system main connections; outdoor lighting; etc.
- Building foundations, structure system, walls, roofs, ceilings, floors, elevators, electrical, gas, fuel, water, sewer, plumbing, sanitary, mechanical, HVAC, chiller, boiler, noise control, lighting, process systems, energy and process material recovery systems, exhaust air and wastewater treatment systems, hazard control systems, explosionproof and corrosionproof issues, instrumentation and control systems, fire protection systems, etc.
- Mini environmental booths; supply, recirculation, makeup, and exhaust air systems; lighting, process mechanical, chemical, electrical, and control systems; production lines; process conveyers; special gas supply systems; acoustics; operating personnel; material and products access doors, windows, or openings; air showers; room temperature, humidity, static electricity, CO₂, and pressurization control systems; fire protection and after-fire recovery systems; seismic design and emergency response facilities, etc.
- Construction service and construction; installation work; system start-up; test, adjust, and balance; commissioning; and handover to operation
- Building management and system operation and maintenance

Iterative Evaluation and Analysis

As the example strategy for minimizing energy use demonstrates, multiple development steps 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 as a whole within the guidelines of the decision criteria.

As each strategy is explored, numerous *what-if* questions must be evaluated and accepted or discarded (see Table 1). Acceptance allows the team to move forward, but does not preclude returning for reevaluation later. Nonacceptance may lead to alternative solutions for the target strategy, or to totally discarding the strategy and moving forward. Discarding a strategy does not preclude returning to it later.

Obviously, IBD 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.

4. 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. See the section on Budget Control under Design Activities and Deliverables for discussion of the differences between these delivery methods.

Effort Shift

IBD requires a departure from the conventional **sequential design process (SDP)** methodology. This change includes a shift in effort during the classical design phases (schematic design, design development, and construction documents), as well as extra, 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 schematic design, 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 design development, 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 analysis (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 (Figure 1). An important point to remember is that implementation of IBD 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 during early design activities must participate on equal footing earlier in the process, so that wholistic issues are considered before it becomes too late for responsible inclusion.

Project Delivery Sequence Focus

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

- Owner planning
 - Determine best-fit construction need
 - Identify least-impact, best-fit siting option
 - Define project objectives

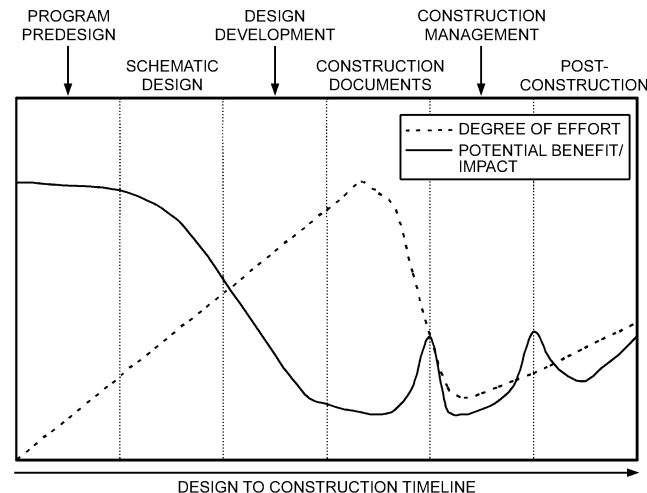


Fig. 1 Benefits of Early Design Collaboration
(Lewis 2004)

- Structure project budget to support integrated building design (IBD) process
- 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

5. DESIGN ACTIVITIES AND DELIVERABLES

Some of the more common design activities and deliverables are affected by IBD. Some schools of thought suggest decoupling these items from integrated practice, but this perspective unfortunately misses the underlying premise that all activities in the project delivery process are interdependent to some extent. 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 IBD 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. 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 2014).

MasterFormat includes some very important sections to address in IBD delivery, including the following in division 01, General Requirements:

- Submittal procedures
- Sustainable design reporting
- Closeout submittals
- Sustainable design closeout documentation
- Facility performance requirements
- Sustainable design requirements
- Facility environmental requirements
- Indoor air quality requirements
- Facility services performance requirements
- HVAC performance requirements
- Integrated automation requirements
- Commissioning
- General commissioning requirements

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 demonstrates 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.

In IBD, the intention is that VE is captured by the strategies and iterations necessary to reach the performance objectives of the project. Because any one solution must satisfy all relevant project objectives, the value of each measure can constantly be assessed. The priority on whole-building performance helps ensure that proposed substitutions are indeed improvements and do not sacrifice performance in a different performance category.

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 IBD 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 fear of liability 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 owners could incorporate some or all of the 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 IBD 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. However, each requires 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. Ideally, in IBD, 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 “[a] quality-focused process for enhancing the delivery of a project. The process focuses on verifying and documenting that the facility and all of its systems and assemblies are planned, designed, installed, tested, operated, and maintained to meet the owner's project requirements” (ASHRAE *Guideline 0*).

Several types of HVAC commissioning processes are available: overall, construction, and existing building commissioning (or retro-commissioning). The commissioning process described here applies to new construction and major renovations.

In new construction projects, the overall HVAC project commissioning approach is recommended. It starts at the inception of a building project during predesign and continues through the design, construction, acceptance, training, operation, maintenance, and postacceptance phases, integrated as part of the entire project.

The owner selects and contracts with an HVAC commissioning authority (CA) at very beginning of the predesign phase. The commissioning authority develops the scope of commissioning and reviews design intent during predesign; during the design phase, the CA reviews the design to ensure the HVAC project accommodates the commissioning process. The CA coordinates with the owner, design engineer, and HVAC contractor, and issues commissioning specifications to address owner requirements, define contractors' responsibilities, and review contractors' submittals. This leads to HVAC construction commissioning, and completion of the rest of the commissioning process.

Commissioning is a rigorous and intense process that should be used when integrated-system-based design solutions are provided. See [Chapter 43](#) for more information.

6. TOOLS

IBD 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 IBD. These are not the only options available: many 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 2014) Whole Building Design Guide web site (<http://www.wbdg.org>).

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 ([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

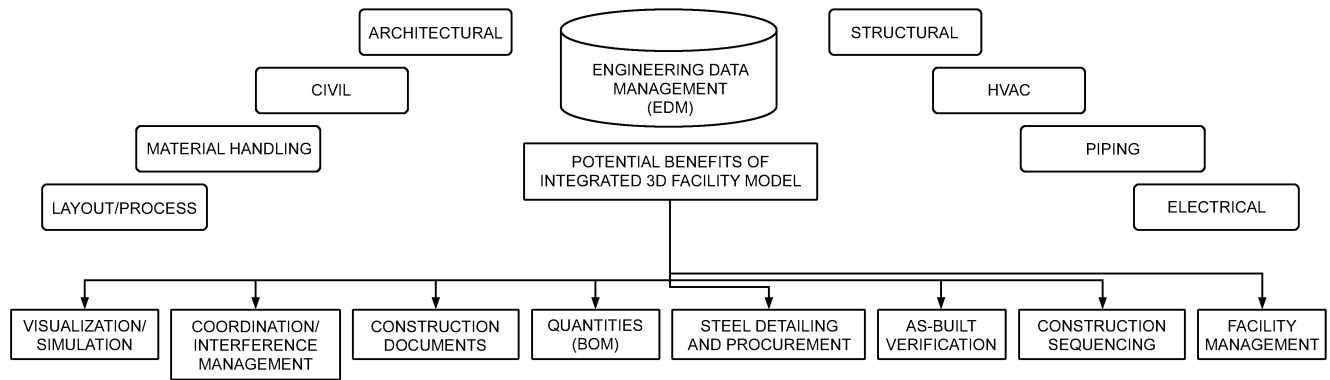


Fig. 2 Overview of BIM Benefits

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.

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., energy simulation, 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 software) 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. 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, 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, etc.

A complete building or facility project design process typically involves various complex conditions such as certain or uncertain, complete or incomplete, natural, artificial, scientific, technical, environmental, and/or economical information; codes, standards, rules, and regulations; and preferences of the owner and their operating personnel. Future computerized IBD and construction would not be only a simple simulation of the project design process, but would also help perform project analysis and diagnosis for optimizing design alternatives and project decisions.

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 interoperable application software under development using BIM.

A major key to the success of these efforts is establishing common software protocols.

The International Alliance for Interoperability (IAI) was formed in 1995 to define and develop standards or protocols as a framework for data exchange, creating the industry foundation classes (IFCs), and gaining ISO recognition. IFCs are maintained by buildingSMART® International, the current name for IAI. The buildingSMART web site (<http://www.buildingsmart.com>) provides the IFC specifications, definitions, and model documentation that can be used to develop BIM interoperable software applications. The latest IFC model is called the buildingSMART data model, codified as ISO/PAS Standard 16739.

The National Institute of Building Sciences (NIBS) established the buildingSMART alliance™ to advance open interoperability and full-life-cycle implementation of BIM, and their National BIM Standard (NBIMS) committee establishes standard definitions for building information exchanges to support critical business contexts. NBIMS addresses the need for a life-cycle view of building supply chain processes, the scope of work necessary to define and standardize information exchange between trading partners, suggestions for a methodology to address this work, and examples of work in progress.

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 tools designed to consider numerous building configurations, various zoning options, and multiple systems. Some of the more common software tools include programs free for download such as the U.S. Department of Energy's (DOE) Energy-Plus or DOE-2/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 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 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 on building orientation, window/wall ratio, envelope insulation levels, daylighting features, and HVAC system selection. 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 energy use. Keep the following points 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.

See Chapter 19 in the 2013 *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 (BLCC) 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 (<http://energy.gov/eere/femp/>).

Chapter 37 contains more information on LCCA.

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RESOURCES

- BLCC www1.eere.energy.gov/femp/information/download_blcc.html
- Energy Plus www.eere.energy.gov/buildings/energyplus/
- DOE-2/eQUEST www.doe2.com/equest