Related Commercial Resources

# CHAPTER 60. INTEGRATED PROJECT DELIVERY AND BUILDING DESIGN

THIS chapter explains potential benefits of integration, implications for project management, and logistics of carrying out an integrated project. Resources in the References, Bibliography, and Resources sections, as well as other Handbook chapters and ASHRAE guidelines and standards, offer in-depth guidance on various integrated project delivery (IPD) application requirements.

Integrated work is done by a cross-functional team of people working together toward a common goal. This concept has been used formally in product manufacturing for at least 60 years and is growing in the building design and construction industry. This chapter discusses two levels of integration, integrated building design (IBD) and IPD, both of which use cross-functional team based project management to promote holistic collaboration by team members during the diverse phases of building project delivery. IBD is embedded within IPD, so the former is included within the scope of the latter. The distinction between these techniques is explained in the Terminology and Process sections.

## 1. WHY CHOOSE IPD?

Owners risk both money and reputation on new buildings. If the building costs too much, is put to beneficial use too late, or performs poorly (by not meeting the needs of occupants or costing too much to operate), the owner stands to lose a great deal. Integrated project delivery is a means to greatly reduce all these potential pitfalls. Integration promises to reduce the risk to the owner that a project will cost more than budgeted, be delivered later than planned, or fail to perform as intended.

There are two models of project development. In **sequential project delivery (SPD)**, designers work within their isolated functional area, as in a bureaucracy. Alternatively, in **integrated project delivery (IPD)**, designers work together with others from all functional areas, as a team. Benefits of integration are best explained by highlighting the distinction between these two ways of working.

The imagery most often used to describe sequential project organization is that of silos. Designers in each function work within their respective silos, isolated from others. Every function (e.g., architecture, HVAC engineering, plumbing engineering, fire suppression engineering, electrical engineering, structural engineering) has its own silo.

Silos exist to make the group efficient. People working in a functional silo are expected to stay busy doing the functional work assigned to them. They communicate with other functions only as necessary to do their work, endeavoring to complete their assignment as fast as possible, either by sending it back to the function that passed it to them, or finishing and passing it on to the next function. The piping designer does not get paid to help the duct designer, and the pipe fitter does not get paid to help the tin knocker or the piping designer.

When architecture decides plans are ready, they send them over the walls of their silo into that of HVAC engineering for HVAC design. If HVAC engineering likes what they receive, they get to work. If they do not, they send the architectural plans back with requests for rework (e.g., making more room for ductwork). Eventually, HVAC engineering passes their work on to others, like electrical and plumbing. Those disciplines may in turn send the HVAC work back for revision. When all the design functions are done, the plans and specification are sent to construction, which often returns them to the designers in the form of change orders because contractors cannot build, or do not understand the plans. Costs increase. Schedules lengthen.

An integrated project is very different. There is only one silo: the team silo. Every function is present and responsible for assisting the others. Architecture never gets a drawing back to make more room for ductwork because the HVAC engineer and the architect work together to size the ductwork and the architectural space it needs at the same time. Furthermore, there is construction expertise available to the design team. The mechanical contractor does not issue a mid-construction change order due to an unbuildable duct design because the contractors were there during design, ensuring the design can be built. Individuals are responsible for doing sound professional work and being good team members, and the whole team of designers and contractors is responsible for making the project efficient.

The work of design and construction gets done in both models. The difference is that a cross-functional team works together from the beginning of an integrated project. They agree on the objectives of their work and how the building will perform when it is done. Then they design the building and all its systems, front-loading collaboration efforts to optimize building system solutions in response to the defined project objectives. Integrated design identifies key issues and addresses them early in design and planning because the people who can see them and solve them are in the room doing the work.

An important point to remember is that integration does not necessarily mean getting more things done early; it means getting the right things done early, and maintaining focus on the required performance during key decisions. Another important point is that integration is not design by committee. Integration is design and construction professionals coordinating their work early in the project, when that coordination can be done most efficiently for the project. The professional work of the architects, engineers and contractors resides only with the professional responsible.

Costs early in the project rise because people are on the job that would have traditionally arrived later. However, because they are there, they can avert and rework problems that would have been more costly to fix later. Thus, costs of later phases (and overall) should be lower. Building performance should also be better because mid-construction design changes to solve problems or reduce cost are made by the whole team before a crisis develops.

# 1.1 COLLABORATION AND TEAMWORK

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 IPD. 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.

IPD extends the scope of design to construction tasks. With construction expertise available to inform the design process, planning can be more specific about materials and methods, more confident around estimating costs, and more accurate with setting schedules. Collaboration between design professionals is extended to constructors and subtrades, eliminating the oppositional relationship between design and construction that is commonly found with design-bid-build approaches. Disagreements may occur, but the IPD environment provides a structure to resolve them, through references to the owner’s project requirements (OPR) and previously agreed-upon project values.

Each project requires a different set of disciplines, though certain roles, like the owner, architect, structural engineer and MEP engineers, are always needed. The selection of team members also depends on whether the project is an IBD or IPD project. These choices are described in the Process section.

# 1.2 TEAMWORK

Team members have two responsibilities:

- To perform their own professional design work developing the agreed basis of design (BOD), recognizing that their work is part of the team’s design for the whole building
- To work for the benefit of the whole team, identifying conflicts that arise between their designs and any of the other disciplines, the OPR, or the BOD; promptly bringing issues to the attention of the other team members; and working toward successful resolutions

Working with a team requires that participants engage in joint decision making. Individual thinking and processes must be formally brought to the team and discussed in the context of project objectives and previous decisions. Having a space for discussing new ideas encourages 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, dissenting views will occur. Emotions must be removed from these events. Evaluations must be made on objective application and support of project objectives. The project team leader should be trained to handle conflict management and dissenting 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

Unsurprisingly, integrated project team formation is more involved than in sequentially designed projects. To create a well established team, the owner needs to be prepared. Integration is not something that happens spontaneously, or that can be achieved at the last minute. Onus is on the owner to organize the team for the work at hand, building up the group as tasks approach. Often, this starts with hiring an integration specialist or design facilitator. As the team expands, it needs to create ground rules for working together and agree on who will be leader for the different phases of development. Often, leadership rotates, following the focus of the development phase. Team formation is discussed in the section on Phase 2: Project Initiation.

The team should consider **colocation** and use of shared development platforms. Colocation of designers and constructors facilitates speedy resolution of conflicts by increasing opportunities for timely collaboration, reducing rework. In a colocated environment, all disciplines get the same information at the same time, and it is easier to get all disciplines working on special conditions together. Colocation is helpful in avoiding conflicts between disciplines and trades, which are common and expensive to resolve. A colocated team has an opportunity to use shared documentation platforms that facilitate coordination and detect clashes between different disciplines. Common development platforms help keep the work of other disciplines visible and offer a common language for project development. Three-dimensional computer-aided design (CAD) systems and building information modeling (BIM) are excellent aids for this.

It is essential that the owner's team has a champion for the integrated project. Early investments are being made in the project that are not common, and without a champion, the focus of the project may drift and compromise the potential of those investments.

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 an understanding of 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.

IPD 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. IPD provides an excellent opportunity to mentor and train supporting staff in system integration, and the opportunity should be fully exploited.

**Participants** should 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.

They should also have experience with optimization techniques. True optimization expertise requires understanding how building systems interact, what elements can be revised 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. Management of outside specialty consultants is an added responsibility that must be factored into the collaborative process.

### Consensus in Decision Making

Typically, teams make decisions by consensus. That means that all share the responsibility for decisions, providing their expertise. Often, consensus is interpreted as "design by committee," which is not the approach used in either IBD or IPD. Rather, integrated design processes depend on sequential leadership, in which the professionals responsible for each of the building systems lead when their area of expertise is discussed, but also contribute their perspectives when other disciplines are in the leadership position. 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 also have a strong technical understanding of how building systems work together and can capitalize on the expertise of all members.

## 2. PROCESS

This section describes methods that, based on the experience of the authoring ASHRAE subcommittee, are sound and may be followed for a successful project. The project overview (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. 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*. Because each phase builds on those before it, the owner should require a *yes* answer to every question in a phase before approving work to begin in the next phase. If a phase is not done well, those that follow are at higher risk of producing an inferior project.

The phase descriptions explain what happens in each of the project phases and guide the reader. They are the how-to guides for completing the phases and delivering what is required for a *yes* answer to each question in the project overview.

This section is not intended to define the only way to carry out an integrated project but to provide guidance to a project team, and must be adapted to each specific project. Every team must establish its own methods through consensus of the team members. These descriptions provide guidance for a team new to integrated cross-functional team project management and inform a design team member about what to expect from others and what others will expect from them.

## 2.1 PHASE DESCRIPTIONS

This section explains the work to be done in each phase listed in Table 1. These descriptions explain methods that, based on the experience ASHRAE Technical Committee 4.10, are sound and may be followed for a successful integrated project. These sections are not intended to define the only way to carry out an integrated project: every team must establish its own methods through consensus of the team members. These descriptions are intended to provide guidance for a team new to integrated cross-functional project management and to inform a design team member who is assigned to an integrated project about what to expect.

- **Introduction:** In general, what happens during this phase?
- **Purpose:** Why is this phase important, what does the work in this phase contribute to the project?
- **Prerequisites:** What must be done before work begins in this phase?
- **Team:** Who are the project team members during this phase? How does membership change during this phase?
- **Work:** What work is done by the team?
- **Sequence of events:** What is the sequence of events, particularly as it pertains to meeting the requirements defined in the integrated building design checklist?
- **Role of design team member:** What is the role of each design team member; how is each person expected to serve as a team member; what must each member deliver as product to the project team?
- **Role of integration leader:** What is the integration leader/commissioning leader's role; how is this leader expected to serve as a team member; what must this person deliver as product to the project team?
- **Performance requirements:** What HVAC systems performance requirements can be affected by decisions made during this phase and require analysis and advice from the HVAC engineer?
- **Tools:** What tools are typically used?
- **Documentation:** What documents are produced?

## 2.2 PHASE 1: PROJECT JUSTIFICATION

Project justification is the owner's activity that determines whether constructing a building will satisfy a need for space and/or a specific return on financial investment. This process is commonly delivered by real estate or project management consultants, but for projects considering an integrated project delivery approach, it is better to develop the same information with a subset of the full IPD team. For speculative projects, this activity requires assumptions about potential end uses, expected revenue, development risks and costs, expected lifetime of the facility, and required return on project investment.

For public sector or owner-occupied projects, a return on investment calculation may be secondary to long-term plans, staffing requirements, organizational image and communications, size of an organization's building portfolio, and funds commonly available for operations and maintenance. Public sector and owner-occupied projects may also be able to entertain longer payback periods than speculative developers. This fact creates an opportunity for IPD and improved building quality.

Project justification sets the conditions for all the work to follow, so it is best if the decision to use IPD is made before the justification work begins. Thus, the foundation for a sound IPD project can be built from the beginning, eliminating the need to convince people to change their minds later, particularly where the project budget is concerned.

Regardless of the state of an owner's initial project assumptions, IPD requires explicit discussion and acceptance of project goals by all participants on the design team. This provides an opportunity to confirm that facility programs and budgets are appropriate.

### Purpose

- Financially justify the project for the owner's approval, before proceeding with the work and the cost of the next phase
- Clearly identify the need(s) for this built space
- Prepare a plan to complete second phase (project initiation), including key team members, objectives, funding required, and schedule

### Prerequisites

For the project justification phase to begin, the owner must

- Have decided to use IPD practice to carry out the project
- Have hired an integrated project leader
- Be willing to actively engage with the design process more than is required by a standard "review and approve" structure
- Be willing to explore alternative approaches to common building design and construction issues

**Table 1 Project Overview**

| Go/No-Go Question | No | Yes |
|---|---|---|
| **Phase 1: Project Justification** | | |
| Has the project justification assessment been completed by a team of highly skilled people, assigned by the owner? | □ | □ |
| Has the team identified and clearly defined a need for this built space? | □ | □ |
| Has the team prepared a plan to complete phase 2, including key team members, objectives, funding required, and schedule? | □ | □ |
| Has the team demonstrated financial justification and secured funding to complete phase 2? | □ | □ |
| **Phase 2: Project Initiation** | | |
| Is there a commitment to high performance? | □ | □ |
| Is integrated building design or integrated project delivery justified? | □ | □ |
| Have the owner's operation and maintenance (O&M) capabilities been documented? | □ | □ |
| Does the owner's O&M staff possess expertise that could contribute to successful outcome of the project? | □ | □ |
| Have these members been identified and included in the owner's team? | □ | □ |
| Has the commissioning agent prepared the first draft of the owner's project requirements (OPR)? | □ | □ |
| Has the project initiation team defined attributes of the concept development and design phases' cross-functional team members? | □ | □ |
| Have members of the concept development and design phases' cross-functional team been recruited? | □ | □ |
| Has a project integration specialist been recruited to join the team? | □ | □ |
| Has the team prepared a plan to complete phase 3, including key team members, objectives, funding required, and schedule? | □ | □ |
| Has the project initiation team demonstrated that there is financial justification and funding available to complete phase 3? | □ | □ |
| **Phase 3: Concept Development** | | |
| Is the OPR complete, documenting clear and measurable targets for building performance, suitable for monitoring building operating performance? | □ | □ |
| Has the team agreed on one set of systems concepts that define the whole building? | □ | □ |
| Have the attributes of specialty resources been defined and are they available as needed? | □ | □ |
| Has the team prepared a plan to complete phase 4, including key team members, objectives, funding required, and schedule? | □ | □ |
| Has the project initiation team demonstrated that there is financial justification and funding available to complete phase 4? | □ | □ |
| **Phase 4: Design** | | |
| Has the integrated team, including design professionals, construction contractors, and owner's O&M staff, worked together to perform design work? | □ | □ |
| Are schematic design documents complete and delivered to owner? | □ | □ |
| Are design development documents complete to the extent necessary for pricing and delivered to the owner? | □ | □ |
| Has the design team demonstrated that there is financial justification and funding available to complete phase 5? | □ | □ |
| Has the team prepared a plan to complete phase 5, including key team members, objectives, funding required, and schedule? | □ | □ |
| **Phase 5: Construction Preparation** | | |
| Is the project price agreed between the owner and contractor(s)? | □ | □ |

| | | |
|---|---|---|
| Do the construction documents include answers to all bid questions and scope of work change agreements? | □ | □ |
| Do the construction documents include all cost reduction design changes and related OPR changes? | □ | □ |
| Does the team agree that commissioning work completed in accordance with construction documents will prove that building performance meets the OPR? | □ | □ |
| Are contractors prepared to perform the commissioning tests and inspections required by construction documents? | □ | □ |
| Are the means and methods for project communication and decision making clearly defined? | □ | □ |
| Has the team prepared a plan to complete phase 6, including key team members, objectives, funding required, and schedule? | □ | □ |
| **Phase 6: Construction** | | |
| Are all systems built and equipment installed in accordance with the construction documents and certified as such in accordance with commissioning requirements? | □ | □ |
| Has the owner’s facility management/maintenance staff made regular visits during construction to ensure maintainability of installed equipment? | □ | □ |
| Are all systems and equipment operating as intended and certified as such in accordance with commissioning requirements? | □ | □ |
| Has the authority having jurisdiction (AHJ) approved the project for occupancy and agreed that all required inspections and tests are complete and satisfactory? | | □ |
| Is the owner O&M training plan complete? | □ | □ |
| Has the team prepared a plan to complete phase 7, including key team members, objectives, funding required, and schedule? | □ | □ |
| **Phase 7: Owner Acceptance** | | |
| Are all systems operating in accordance with the OPR? | □ | □ |
| Does the owner have all documentation required to operate and maintain the building? | □ | □ |
| Have all required documents and maintenance procedures been incorporated in the owner’s maintenance management system? | □ | □ |
| Have the owner’s O&M people been trained in the proper operation and maintenance of the integrated whole-building systems? | □ | □ |
| Is the owner prepared to operate and maintain building performance in accordance with the OPR? | □ | □ |
| 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? | □ | □ |
| **Phase 8: Use, Operation, and maintenance** | | |
| Does operating performance, under normal use and occupancy, meet the OPR? | □ | □ |
| Are O&M personnel in place and prepared for ongoing operation? | □ | □ |
| Do all team members agree that the project is complete? | □ | □ |
| Is the owner prepared to operate and maintain building performance in accordance with the OPR? | □ | □ |

## Team

The project justification team is small and able to, quickly and at low cost, collect and analyze enough information to decide whether the project is worth pursuing further. The team must include

- Team leader (may be the integration specialist or owner)
- Owner (and/or an employee authorized to make decisions and able to obtain information)
- Integration specialist
- Financial analyst
- Expert in documenting occupant requirements (facility planning/commissioning basis of design fundamentals); could be the commissioning agent or integration specialist

The team may wish to augment their knowledge by consulting with other experts for information. Areas of expertise may include

- People with special knowledge of particular building types

- Local real estate conditions for various markets
- Details of local land use planning objectives and regulations
- Building commissioning
- Building operations and maintenance
- Building finances, including tax applications
- User groups varying with building type
- Knowledge of available government and utility incentives
- Construction cost estimating
- Structural design
- HVAC design
- Plumbing and fire protection systems design
- Electrical systems design
- Civil design
- Building science
- Natural lighting and acoustic design

## Work

This phase begins when the owner believes that a building project is warranted. The project team first gains an understanding of the owner's hypothesis and determines either that it is valid enough to justify work in the next phase, or that it is not valid and no further effort is justified. The tasks include (but are not limited to)

- Collecting information on the market for the proposed building
- Identifying who would occupy the proposed space(s) and their needs
- Determining if and how their needs are being met now
- Determining what needs are not being met
- Defining what added space or existing space upgrades (adaptive reuse) would satisfy unmet needs
- Determining how the added space or existing space upgrades (adaptive reuse) could be used to satisfy unmet needs; evaluating if other spaces could meet the need by consolidation
- Estimating the cost of producing the new spaces or upgrades
- Estimating the worth of the new spaces or upgrades in terms of revenue, productivity, goodwill, etc.
- Deciding whether the worth justifies the cost (rough numbers are good here)
- Identifying the skills needed from team members who would complete phase 2
- Identifying specific individuals and firms who would make up the project initiation team and the cost for their work
- Preparing a plan for phase 2 work, including objectives, personnel, budget, and schedule
- Securing plan approval and necessary funding

If the owner already owns the land but is open to how it will be used, then this work may begin by exploring different purposes and include one or more viable options for further investigation.

Information sources for project data depend on the type of project. For an owner-occupied building, the market information is mostly internal. Market information for tenant-occupied buildings is externally focused and includes speculative buildings the owner intends to sell on completion.

Typically, the total project expenditure is divided into two types of costs. **Soft costs** include design consultancy fees, specialty testing and expert fees, and other costs arising from documenting the site and the proposed design. **Hard**

**costs** include construction cost (including labor), plus the applicable municipal, state or provincial, and federal regulatory fees. Bank financing and carrying costs may also be included in the assessment of hard costs. Designers must justify the soft costs and estimate hard costs as accurately as possible to assist with the development of the project's financial outline.

At this stage, an awareness of how to bring funds to the project is important. For example, there are federal and state tax incentives, Internal Revenue Service (IRS) benefits from cost segregation studies, solar or renewable energy usage incentives, and low-interest loans available for energy-efficient projects. Utilities often have incentives or product rebates for energy efficiency measures, which are driven by regulatory or demand management requirements. There can also be incentives for going through the IPD process. When combined, these incentives and benefits can dramatically reduce hard costs. Any team member may bring knowledge of incentives for building construction to the team; it is not solely the responsibility of the owner.

## Sequence of Events

The sequence of events, particularly as regards meeting the requirements defined in the IPD checklist, is

1. Owner decides to adopt IPD to take advantage of the method's benefits and to differentiate the building from the regular market.
2. Owner assembles the project justification team.
3. Project justification team assesses the potentials of the project in several possible variations.

Should viable versions of a project be presented, the project justification team

- Prepares documentation outlining the nature of the project and demonstrating the project viability and benefits. This documentation includes descriptions of performance conditions that will inform the initial basis of design documents.
- Prepares a plan for phase 2.

## Team Roles

**Design Team Member.** The typical MEP engineering group may not be a member of this intentionally small and low-cost team, but could be asked to consult with the team to create rough projections of cost, performance, and service life of building elements.

At this stage, there is an idea (but no design yet) about the project, and the site is typically known. Projections for building performance that support the estimate for the return on financial investment must be developed. Building cost estimates and performance expectations are usually based on the owner's past projects of a similar type, or minimum code-compliant design. However, the benefits of state-of-the-art (SOA) systems, which can provide better comfort, efficiency, noise levels, return on investment, etc., should be recognized before budgets are fixed. The benefits can outweigh budgetary constraints when evaluating SOA systems, and at this junction budgets are more flexible.

A member of the design team may be called upon to explain such things as differences from systems used in the owner's last similar project, a minimum code-compliant building, or the improvements possible with contemporary HVAC technology and design practices. This explanation must define the differences between types of systems, what they offer in terms of higher productivity due to better conditions for occupants, lower operating costs due to energy-efficient design or more robust equipment, and costs of construction. (*Note*: the team should have experts in building performance and cost estimating to help with this work).

In this phase, any design team member asked to participate needs good verbal communications skills, flexibility in developing alternative performance scenarios, and good technical writing skills to communicate the relevant information to the team. He or she will also benefit from a developed ability to work with others and the capacity to draw on the experience of other design disciplines to quickly produce a thorough analysis.

Systems likely to be evaluated are

- Building envelope characteristics such as percentage openings, U-values, and water management strategies
- Ventilation systems, including energy reduction and energy recovery
- Cooling systems
- Heating systems
- Energy transfer (between heating and cooling) systems such as variable-refrigerant-flow (VRF) systems
- Air distribution systems

**Integration Leader.** The integration leader leads the effort to determine and document what performance requirements will help meet the needs of the intended occupants. This is the first rough pass at this information and captures things such as energy consumption targets that might require higher-cost construction, more comfortable conditions to increase worker productivity, etc. This information is the foundation of the basis of design documents used by commissioning specialists.

The integration leader may be the project manager for this phase of work. That person is also be instrumental in planning the integrated project delivery process and identifying the required team members.

## Performance Requirements

Performance requirements can be affected by decisions made during this phase and require analysis and advice from the HVAC engineer regarding

- Indoor air quality
- Indoor environmental conditions that affect comfort, productivity, and safety of occupants
- Operating costs, including energy and maintenance
- Acoustic performance
- Air quality and safety of neighboring properties
- Greenhouse gas (GHG) emission requirements (refrigerant selection)

HVAC systems performance requirements are relative to the overall quality of the facility being proposed. For commercial buildings, facility quality is related to the target rent, which is assumed to be in the range of the target market. For institutional projects, high-quality facilities are often specified, but potentially outside of the cost range of the project. Regardless of facility quality, building codes require compliance with, and sometimes incremental improvement from, ASHRAE *Standards* 90.1, 62.1, 62.2, 55, etc. As these standards are improved in the pursuit of reduced resource consumption and more reliable design and operational performance, facility quality levels are increased. If the owner sets a budget for the project based solely on experience, opportunities for better, more marketable spaces with lower operating costs may be lost.

## Tools

Tools useful to this phase validate assumptions regarding building performance and capital or operations costs. Historical data on the energy performance of similar building types in the same climate zone is a key starting point. Similarly, historical data on local construction costs inform understandings of predicted costs. Real estate surveys of market conditions and rental costs per unit area provide data for the revenue side of the equation.

Energy use intensity figures in energy units over areas, such as kilowatt hours per square foot ($kWh/ft^2$), are easily multiplied by gross building area to create operational estimates. National databases of energy performance are available where the owner does not have access to a portfolio of buildings in the region. Examples include

- U.S. Energy Information Administration: CBECS
- Natural Resources Canada: National Energy Use Database
- ENERGY STAR: Portfolio Manager

Standard estimating handbooks are also used to identify construction costs. In the absence of a design, indicative estimates on a unit floor area or building volume basis are common. Common estimating references include RSMeans *Building Construction Cost Data* and Hanscomb's *Yardsticks for Costing*.

For the revenue side of the ledger, reports on costs from real estate associations and brokers support predictions of revenue for a potential project. Unit-area-based costs are the finest level of detail required. Attention to the terms of rents is crucial, because the opportunities for return to the owner vary greatly between all-inclusive and triple net leases. Data from the local chapter of the Building Owners and Managers Association (BOMA) or recent reports from brokers are used. Potential incentives for specialty applications can be recorded, but may need to be reduced by a factor representing the risk of the final project not qualifying for the incentive, or the incentive amount being reduced.

## Documentation

- Financial justification documents required by the owner to secure financing for the project

- First version of owner's project requirements (OPR), including first version of building performance requirements
- Plan to complete phase 2, including key team members, objectives, funding required, and schedule

## 2.3 PHASE 2: PROJECT INITIATION

The existing team from phase 1 is expanded to prepare a more detailed project description, providing the scope of work for design professionals in preparation for design and development work. Ideas from phase 1 are developed in greater detail and scrutinized for their continued relevance.

### Purpose

- Assess the owner's resources and identify the internal and external participants needed for fully integrated project development
- Continue development of a more complete OPR, replacing assumptions made in phase 1 with information developed by the phase 2 team
- Decide if the project will be delivered by an IPD method or other integrated approach
- Prepare the communications materials that explain the IPD process for incoming new participants, including designers, constructors, and potentially investors
- Secure funds to hire the project team
- Recruit the team experts who will continue the project

### Prerequisites

- There is a viable project to be developed.
- A preliminary project description exists that
  - Includes building size and quality.
  - Identifies the intended occupants of the building, the approximate performance they will need, and what they will expect from the spaces.
  - Documents early ideas about building performance. The form of the information may be related to assumed operating costs and replacement cycles rather than explicit system performance requirements.
- An approved, funded plan for completion of this phase exists.

### Team

During this phase, the team grows from the initial members of phase 1 to the extended group that will complete much of the work in phases 2, 3, and 4. At the beginning of the phase, the team includes

- Team leader (may be the integration specialist or owner)
- Owner (and/or an employee authorized to make decisions and able to obtain information)
- Integration specialist
- Financial analyst
- Expert in documenting occupant requirements (facility planning/commissioning basis of design fundamentals); could be the commissioning agent or integration specialist
- Facility operations and maintenance specialist

Team makeup at the end of phase 2 and start of phase 3 depends on whether the project will proceed as an IPD or an IBD project. For IPD, recommended team members include

- Owner-appointed project manager (owner employee preferred, *not* an external project manager);
- Integration specialist
- Facility operations and maintenance specialist
- Commissioning agent
- Architect
- Structural engineer
- Civil engineer
- General contractor or construction manager
- Mechanical engineer (HVAC, plumbing, fire protection, building management/controls system)
- Building sciences engineer
- Mechanical contractor
- Electrical engineer (power, lighting, fire alarm, communications, etc.)
- Electrical contractor
- Cost estimator
- Energy analyst or modeling specialist

If the project is to be limited to an IBD, the contractors would be excluded from the team. The rest of this chapter assumes that an IPD project delivery method has been adopted.

Most of the disciplines required for the whole project are represented here. Some specialty design or construction teams may be added in phase 3 if necessary. This might include tenants/occupants (if fit-out is part of the project), an acoustic specialist, lighting specialist, landscape architect, LEED specialist, scenographer, etc.

## Work

The team must research and document the building performance necessary to satisfy the needs of all project customers (owner and occupants). The team self-organizes to ensure that information is approached in an orderly fashion and that all relevant opinions are incorporated. Investigate the owner's capacity for managing innovation with respect to state of the art systems. The first formal draft of the OPR is prepared in this phase. The objective of all design team work is to produce a building and systems that meet the performance targets set forth in the OPR.

- Consider the rough OPR from phase 1 and improve it by eliminating unvalidated assumptions and replacing them with factual information provided by the phase 2 team.
- Owner assesses the capabilities of personnel available from the owner's O&M organization.
- Owner identifies and recruits personnel.
- Decide the project delivery method: IBD with a conventional tendering based on a complete building design package, or IPD with a construction management and guaranteed maximum price (GMP) approach.
- Document the expectations and participant responsibilities for IPD.
- Prepare a charter of values or project charter that establishes priorities for interdisciplinary responses to the OPR. (See Terminology section for definitions.)
- Identify and recruit design team members from architectural and engineering firms.
- Identify and recruit construction leaders.
- Negotiate fee agreements with all team members to support the IPD process, educating the potential team members about what is expected.
- Register with programs that provide incentives for IPD.
- If the project team is going to colocate, establish the location and space requirements of the workplace, then lease space or arrange internal resources to house the design team activities.

- Review IT resources of the assembled team and decide on the IT platform and programs to be used.
- The newly recruited team reviews and validates the project justification, now estimating project cost and value based on more in depth understanding of what the owner and occupants need.
- Owner decides whether spending to complete phase 3 is justified.
- Prepare a plan to complete phase 3, including resources, schedule, and budget.
- Secure owner approval to proceed with concept development.

## Sequence of Events

1. Document owner’s O&M capabilities to help identify necessary new participants.
2. Identify required design resources.
3. Decide on project delivery method (IBD or IPD) based on nature of OPR.
4. Recruit expanded and final phase 2 resources.
5. Prepare initial charter of values for the project in consultation with the expanded team.
6. Decide if the team will colocate, or otherwise define working approaches to facilitate integration if physical colocation is not planned.
7. Identify and secure colocation space if required, or establish equipment setup and system to support virtual colocation if the team members are geographically distant.
8. Prepare the next edition of the OPR based on updated assumptions.
9. Confirm that there is a viable project and that funding should be made available for concept development.
10. Prepare a plan for phase 3 and obtain owner approval to prorole of design team member. As the project is just being started, no time has yet been spent on concept design. This time is best used to lay out as many potential options as reasonable and explore how they respond to the requirements of the space or occupants. This is the time for conventional goal setting meetings, where the owner and designer discuss preferred systems and the challenges of specific applications in the project as described.

In phase 2, the owner’s requirements are first assembled in an OPR document. The team helps develop the OPR by noting the usual contributions made by their disciplines, and the implications for operations and maintenance or cost. Where the preliminary OPR creates special conditions needing extra attention from the designers, those items need to be flagged for further discussion.

A design team member will likely be asked to consult with the team to create the rough assumptions of cost, performance, and service life, made for building services elements.

A team member should review the performance requirements in greater depth, revising (if necessary) the phase-1 recommendations based on new information. Preferably, this should be done by a member who also participated in phase 1, but can also be done by a new team member.

In this phase, a prospective design team member needs good verbal communications skills, flexibility in developing alternative performance scenarios, and good report or letter-writing skills to present relevant information to the team.

Because concept design has not yet begun, there are no systems to evaluate, but there are strategies for building services that form part of the OPR. The designer needs to address the pros and cons of a variety of strategies when developing the OPR. Specifically, the HVAC engineer will use the completed OPR as the basis of concept development, and will likely present desired performance outcomes such as

- Building envelope characteristics typical to the standard building types used in financial planning, including percentage openings, U-values, and water management strategies
- Ventilation strategies, including energy reduction and energy recovery
- Cooling strategies (air distribution, radiant, desiccant, district, central, local)
- Heating strategies (air distribution, hydronic distribution, steam, district, central, local)
- Energy transfer (between heating and cooling systems) strategies

### Team Roles

The **integration leader** facilitates the cross-functional teamwork and may be the project manager for this phase of work. This person is also instrumental in planning the integrated project delivery process and identifying the required team members.

The **commissioning agent** works closely with the owner and owner's O&M staff to document ideas from discussions of building services strategies in a form appropriate for the OPR and as directions for future designers.

### Performance Requirements

Performance requirements are formally set during this phase and require analysis and advice from the HVAC engineer on

- Indoor air quality
- Indoor conditions that affect comfort, productivity, and occupant safety
- Operating costs, including energy and maintenance
- Acoustic performance
- Air quality and safety of neighboring properties
- Refrigerant quality (in case of industrial refrigeration)
- New conditions or service requirements that have arisen during development of the OPR

### Tools

- Marketing research tools to determine needs of owner and intended occupants
- Cost estimating tools (both construction and life-cycle costs)
- Various simulation tools

### Documentation

- Updated financial justification documents required by the owner to support new or expanded financing for the project
- OPR, completed as necessary to begin concept development of all building systems
- Fee agreements that reflect work required by an IPD project, executed by firms committing employees to the project team
- Plan to complete phase 3, including key team members, objectives, funding required, and schedule

## 2.4 PHASE 3: CONCEPT DEVELOPMENT

Concept development begins the design process, wherein the assembled team identifies planning configurations and building services systems that respond to the OPR. The selected final concept is later developed into the project to be delivered.

For the first time, diverse specialists come together and work to cover all aspects of building design. The team considers reasonable ways (concepts) to meet the OPR, compares them, and selects the concepts to be developed in technical detail in phase 4. For an IPD project, the discussion of concepts includes the construction expertise of a general contractor or construction manager (and possibly major subcontractors), which brings greater security to ideas regarding constructability, cost, and scheduling. If necessary, the team brings in specialists in select concepts.

### Purpose

The purpose of this phase is to select the set of spatial configurations and building systems concepts to be designed and built (the BOD). Key objectives to meet that end are

- Developing different aspects of the OPR in greater depth
- Considering various concepts for accomplishing the OPR
- Selecting the systems concepts that will comprise the BOD

## Prerequisites

- Phase 2 work is complete and accepted by owner.
- Funding for phase 3 is approved (first draft of the OPR is complete and owner interest in the IPD has not changed).
- People assigned to the project team are empowered and authorized by their employers to make timely decisions. They are not required to secure approval from superiors before contributing to team decisions.
- The designers are engaged and supportive of a multidisciplinary approach to design.
- The assembled IPD team has agreed on a development approach to the work, responsive to the OPR. For example, a project with net-zero energy goals would adopt a passive design approach that minimizes loads before designing systems to serve anticipated loads. Varying iterations of concepts are to be expected as they mature.

## Team

The same team assembled during phase 2 continues work throughout phase 3.

## Work

During concept development, the design team works together in earnest. The deliverables are an updated OPR and a BOD. To produce these documents in an IPD context, much work must be accomplished by the team:

- Hire new team members (firms and individuals) needed to complete phase 3.
- Complete the OPR by researching the performance requirements in greater detail and more broadly. This may include thorough marketing research to define required building performance for the intended occupants, carefully assessing the exact uses and occupancies, and producing detailed definitions of the conditions required to satisfy the market place expectations and statutory (code) requirements.
- Agree on the method and measures the team will use to select the concepts for the BOD.
- Prepare a reasonable set of alternative concepts for each system to create the space environments.
- Perform analysis as needed to quantify differences between competing concepts in terms of the measures agreed upon. Examples include
    - Expected durability of building systems, including enclosure
    - Tightness of environment control
    - Energy conservation
    - Initial cost
    - Operating cost
    - Fit of owner’s O&M capability with system O&M requirements
    - Flexibility for future changes
- Select types of systems to be designed and built.
- Prepare the comprehensive whole-project BOD to document the selected concepts.
- Identify and resolve any conflicts between the OPR and expected performance of selected systems. Update the OPR accordingly.

## Sequence of Events

In phase 3, the team participates in regular multi-stakeholder (cross-functional) meetings with clear objectives and agendas. Participants develop concepts to accomplish the OPR. Content of the meetings should be tailored to the project; however, some elements are true for all projects.

Meetings are working time for developing concepts, rather than simply presentation venues. They are focused thematically and develop responses to specific questions live in the meeting. Where questions cannot be immediately answered, the issues are identified for work to be undertaken outside the meeting and returned to in the next agenda. The team may wish to cascade issues, wherein a topic is introduced in one meeting, a response is presented in a second meeting, and a decision is made in a third meeting, allowing time for fine tuning of the scenario or issue between meetings.

A kickoff meeting introduces all participants, presents the OPR, and gathers first thoughts about preferred systems, materials, and methods. The team must first organize itself for the work at hand; establish ground rules; agree on site for colocation if appropriate and get work spaces set up; select the phase team leader; and agree on how the team will make decisions throughout the project. A charter of values containing the hierarchies of values to be used and descriptors of the project to be used by all must be established and documented, formally setting out the objectives of the project. This agreement can be consulted later to resolve issues stalemated at finer levels of detail.

The early meetings ensure that everyone understands project issues and concerns. During these meetings, everyone hears the same information at the same time and gains an understanding of all project aspects, including those outside of their own expertise. The team must first assess the completeness of the OPR delivered in phase 2. If necessary, learn more about user environment requirements for specific spaces, including safety, productivity and comfort. Ensure that the OPR includes the environment or system performance attribute by name, the measurable acceptance limit(s) that define success, and the method to be used to measure performance for owner acceptance of the project.

After establishing an acceptable level of understanding of the OPR, the team must agree on the criteria that will govern the selection of systems from the list of options. At minimum, these include

- Performance relative to OPR
- Initial cost
- Operating cost
- Constructability
- Life expectancy and degree of difficulty to maintain performance
- Availability of the required materials, equipment, and constructors

**Strategy Development.** An integrated project is concerned with all aspects of building performance, but still needs a way to work through the different building systems to avoid unnecessary rework. Each system influences the performance of the others. When looking at controlling energy consumption, and therefore operating costs, some preliminary calculations (e.g., boiler sizing, heating distribution sizing) can only be done after understanding what the building enclosure efficiency is. Accordingly, following a passive load reduction design path is a generic starting point for effective design of heating and cooling services. Ventilation and plumbing design come from the design building population, and are somewhat independent of the hierarchy. In all circumstances, objectives such as energy efficiency are secondary to providing the facility requirements set out in the OPR and refined in the charter of values. For passive energy design in cold climates, the order of events is as follows:

1. Minimize building envelope load by optimizing thermal properties of the opaque envelope with the area and thermal properties of fenestration.
2. Minimize electricity consumption for lighting by coordinating lighting requirements with fenestration and matching the size of control zones to anticipated daylight conditions. Use occupancy-based controls where lighting is not influenced by daylight conditions
3. Minimize connected internal electrical loads using small control zones and occupancy-based controls.
4. Separate ventilation services from space heating and cooling. Optimize ventilation energy requirements, considering heat recovery on exhaust and relief air, fan motor performance and controls, and static pressure in distribution; consider space planning strategies that facilitate cross ventilation.
5. Optimize potable water supply layouts for low pressure losses. Consider use of the lowest-flow plumbing fixtures available at reasonable costs. Use efficient pumps.
6. Serve remaining heating loads with optimized boiler and pumping efficiency, plus optimized distribution layouts with low pressure losses for hydronic systems. Look for low-pressure air systems and optimized fan design in air-side systems.

7. Optimize delivery of cooling, considering use of outdoor air or radiant cooling. Consider heat rejection chillers providing preheating for domestic hot water or boiler water. Coordinate cooling strategies with ventilation strategies for use of outdoor air.

In subsequent meetings, the potential detailed concepts for inclusion in the project are identified and assessed. The team lists the types of systems that would be reasonable for the type and location of the building. Teams usually begin by deciding on the concepts for passive elements of the building, which are those that contribute to or detract from performance only by their existence (e.g., amount of insulation in the building envelope). Examples include

- Building location and orientation
- Presence of site issues such as soil contamination, infrastructure quality issues, or wetland areas requiring offsetting measures on other sites
- Availability of municipal infrastructure, potable water, sanitary sewers, stormwater management, natural gas, electricity, and capacity of those systems
- Potential for renewable energy installations
- Transportation issues around the site, including access for equipment and materials, and impacts on adjacent neighbors and surrounding neighborhoods
- Special requirements for control of light trespass and noise generation
- Foundations: pilings, raft slab on grade, foundation walls with footings, etc.
- Structure: steel frame, concrete, wood frame, etc.
- Roof: sloped, flat; insulation types; water barrier types
- Ground insulation, moisture and air barrier systems
- Exterior walls: type and amount of fenestration, type of entryways and performance as infiltration barriers, opaque wall systems and their moisture, air and thermal barrier performance
- Ventilation systems: operable windows, mechanical; various types
- Heating: hot water, steam, electric resistance, direct-fired gas, heat pump/radiators, air handlers
- Cooling: chilled water, direct expansion, heat pump, swamp coolers; if chilled water, then water or air cooled;
- Energy recovery and reuse: VRF heat pumps, energy recovery wheels, heat pipes, air-to-air heat exchangers, circulating condenser water system
- Service hot water: district steam, gas fired, electric, solar
- Electrical power: utility, solar, wind (or combination); single-phase, three-phase (and at what service voltage)
- Lighting: type(s) and controls
- Control system: building management system, stand-alone equipment controls; including all systems such as HVAC, lighting, plumbing, electrical power or limit to HVAC systems
- Elements serving special conditions unique to the OPR, etc.

In each meeting, individual concepts are developed and ranked according to their perceived value. Once a concept is completed it should be evaluated and compared, based on the charter of values established in the first meeting. Preferred options are identified for further development. If required, specialists may be engaged. When analyzing and discussing each topic, the team must

- Determine how the concept responds to the performance and operating attributes of each building system.
- Ensure that each attribute has a measurable target value and acceptance range.
- Define the method to be used to measure each attribute.
- Decide whether any selected systems require specialists to be part of the team. If so, identify these specialties and recruit the needed team members.
- Based on the definitions, rank the various options, using selection criteria, and agree on the systems to be included in the building. The set of concepts selected is now the BOD for the project. With the BOD defined, the

team prepares a cost estimate for the project using the selected systems, validates that the project is financially viable, and amends the OPR if the selected systems will either enhance or diminish the expected performance. These changes must be made with the full knowledge and agreement of the owner and entire project team.

- Finally, prepare a plan to complete phase 4, including key team members, objectives, funding required, and schedule. Secure owner approval of the plan.

## Team Roles

**Design Team Member.** As for all phase-3 participants, the design team member’s role is to participate in discussions about all disciplines and lead discussions in their specialty. Throughout the meetings, the team member will be called to

- Contribute to discussions developing the OPR, providing reasonable performance targets based on the type of building and systems to be included.
- Contribute to the BOD content.
- For the **HVAC engineer** specifically: be a key member of concept identification and selection, providing guidance on which HVAC systems (with relevant building envelope requirements) are reasonable to consider based on climate, type of building, etc. Identify any promising new HVAC systems and approaches.
- Assess the ability of each system to meet the OPR.
- Be a present and active contributor to the entire design process, providing opinions of how systems will be affected by all project decisions.
- Provide guidance and opinions about team decisions in which members have experience, even if it is outside their specialty.

**Integration Leader.** In this phase, the integration leader needs to have a strong overview of how all building systems work together. Senior architects, senior project managers, senior commissioning specialists, general contractors, or construction managers may have the necessary skills, depending on the OPR and team members available. The integration leader facilitates concept planning meetings by

- Setting meeting agendas in coordination with the owner and designers
- Identifying the various participants required for the meeting, including the duration of their participation
- Ensuring that all participants contribute to and are heard in the meeting
- Challenging participants to properly investigate all options on the table, especially when they appear to be stuck, asking sometimes difficult questions
- Documenting interim results, issues raised, and challenges presented
- Updating the OPR and charter of values with the input of all stakeholders in response to changes agreed during design
- Preparing meeting minutes that identify next steps

Additional integration tasks are required in support of the meetings. These include

- Identifying where new expertise or additional participants are required
- Managing OPR revision documentation
- Managing the assembly of concept documentation, the BOD.

## Performance Requirements

During IPD meetings, using the OPR as a basis, the team must determine the performance requirements to be met, as well as how they will be measured. Performance requirements to be developed include

- Building envelope: thermal and moisture control, plus airtightness performance of whole building

- Indoor environment requirements: acoustical quality, ventilation rates, materials used, location of makeup air intakes, etc.
- All HVAC systems and their ability to meet the OPR and be adaptable for long-term changes to technologies and building use
- Lighting systems and their effect on heating and cooling loads
- Domestic (service) water heating and other plumbing systems (particularly for lab and industrial buildings)

## Tools

- Planning tools for multi-stakeholder, multicriteria decision making (checklists, flip charts, sticky notes, roles of sketch paper, markers, etc.)
- Investigative tools such as mind-mapping software (or freehand drawing)
- Marketing research tools to determine needs of owner and intended occupants
- Computer visualization, model building, and presentation tools such as SketchUp (www.sketchup.com)
- Construction costing documentation (unit area basis)
- Simple energy modeling (shoebox models) or spreadsheets for design day assessments
- A meeting room environment that will facilitate brainstorming sessions, breakout sessions, presentations
- Refreshments and snacks

## Documentation

- Updated OPR document that captures improvements made and changes agreed to as various concepts were selected and potential conflicts with the OPR were identified and resolved
- BOD document that captures the agreed set of concepts for
  - Site plan
  - Building envelope, including fenestration and door to wall ratios
  - Rough floor plans, sections, elevations
  - Single line schematics for ventilation, heating distribution, cooling distribution, lighting, and main power distribution
  - Selected systems for:
    - Ventilation
    - Space heating
    - Space cooling
    - System controls and communications
    - Electric and natural lighting
    - Electrical power and communication
    - Domestic (service) hot water
- Updated financial justification documents required by the owner to support new or expanded financing for the project
- Fee agreements that reflect work required by an IPD project, executed by firms committing employees to the project team
- Plan to complete phase 4, including key team members, objectives, funding required, and schedule

# 2.5 PHASE 4: DESIGN

Phase 4 produces the design of the building to be constructed, adequately completed for accurate cost estimating. The team expands the concepts into full designs, including design of specialty systems, updating the OPR as they identify gaps and opportunities.

Keep in mind that both the OPR and BOD are living documents that will likely be amended as design progresses.

## Purpose

- Complete the design documents ready for competitive pricing for IBD projects.
- Complete the design documents and cost estimate for use in construction contracts.

## Prerequisites

- OPR is complete
- BOD is complete
- Funding is approved for phase 4
- All team members needed for phase 4 have been assigned and/or hired
- All team members are committed to the integrated work process

## Team

- Integration specialist
- Empowered owner employees authorized and qualified to make decisions immediately as required by designers
- Occupants or user group representatives
- Design professionals: facility programming specialist, architect, landscape architect, civil engineer, mechanical engineer, electrical engineer, energy analyst/modeler
- Commissioning agent
- General contractor/construction manager, mechanical contractor, electrical contractor
- Specialty contractors: prefabricators, facade specialists, renewable energy designers and installers, testing labs, building performance test contractors, controls specialists, building automation specialists
- Incentive program representatives from energy or water utilities where programs are available

If the project is limited to IBD, then the constructors would be excluded from the team.

## Work

- Prepare a target design cost and construction budget, and update it regularly as work progresses. It will become a more accurate predictor of the final project cost as design work progresses and exact design elements are defined. If the cost is deemed to be unacceptably high, consider ways to reduce the cost of the subject system without diminishing building performance. If a compromise between cost and performance must be made, then document the agreed change to acceptable performance, acceptable cost, or both. Iterate the design and cost estimating until the project is financially viable.
- If there are misunderstandings of the scope of work in the design documents during costing, improve clarity of the documentation so the same misunderstanding does not arise during construction.
- Confirm the order of development for the building systems, following the BOD and with understanding of the impact of one system on others in the whole building.
- Expand concepts presented in the BOD to represent the correct areas and volumes, allowing accurate sizing of building services.

- Complete the schematic design:
  - Flow diagrams of everything relevant to the developed design
  - Initial building services concepts are sized for optimum capacity and distribution systems are planned
  - Flow of people in/out of building and spaces; their activities while occupying spaces; relationships to OPR/BOD environment conditions (may amend OPR/BOD for needed clarifications); internal transportation systems like escalators and elevators
  - Flow of work processes and materials that rely on building systems such as process heating and cooling systems
  - Flow of energy via heating and cooling systems (heating and cooling loads) and via energy reuse systems such as heat pumps and energy recovery units; electrical power for space loads and lights
  - Flow of ventilation and exhaust air
  - Flow of water for use and consumption
  - Flow of waste (sewage, trash, process scrap)
  - Flow of people, air, power, fire control/extinguishing fluids in response to emergency situations (fire and evacuation)
- Complete design development:
  - Develop systems concepts agreed to in phase 3 and documented in the BOD into complete systems designs to produce and facilitate the flows defined in schematic design and satisfy requirements for space environments defined by the OPR.
  - Complete plans and specifications for all building systems and equipment, including how to confirm they meet performance requirements before owner acceptance.
  - Have designers coordinate the work in multidisciplinary review sessions as the system descriptions mature.
  - Have construction specialists lead the design team in constructability reviews of the documents, as the descriptions of the building systems are approaching completion. Designers revise the documents where constructability can be improved.
  - Have owner’s O&M staff lead the team in operational review (see the Terminology section) of the systems as the design matures.
  - Prepare the commissioning protocols to be followed to prove that the building and its engineered systems meet the OPR’s performance requirements.
  - Produce the construction documents (plans, specifications, and commissioning protocols) that will govern construction. Only minor revisions will be required from this phase forward, such as those needed to address contractor questions and satisfy code officials.
- Finalize cost estimates based upon the developed design.

## Sequence of Events

1. Organize the team and work practices.
2. Prepare a target design cost and construction budget. Update the cost estimates while making design decisions.
3. As design progresses, ensure that conflicts between systems or with the OPR or BOD are discussed and resolved by the entire team. If compromises are necessary, document them and revise the OPR or BOD, securing approval from the owner. These changes must be made with the full knowledge and agreement of the owner and entire project team.
4. Prepare and document the schematic design and ensure that the entire team agrees that it is complete and correct.
5. Coordinate locations and operations of building systems.
6. Prepare developed design documents.

7. Undertake constructability reviews as building systems definitions progress.
8. Reiterate these steps as necessary to create the complete integrated design.
9. Prepare a plan to complete phase 5, including key team members, objectives, funding required, and schedule. Secure owner approval of the plan.

## Team Roles

**Design Team Member.**

- Work closely with building scientist to thoroughly understand expected envelope performance and resulting loads on HVAC systems.
- Ensure that all information needed to design the systems (HVAC, water, structure, etc.) is captured and reflected in the schematic system diagrams.
- Ensure that systems are designed well and reflected in the final design documents.
- Ensure that complex systems that work across disciplines are well integrated and that the design documents explain the integrated system(s) for both construction and O&M by the owner after occupancy. Examples include
    - Smoke control systems: it is critical that smoke control systems be integrated between HVAC, building management system (BMS), fire alarm, electrical power, and architectural egress pathways. A subteam to work on these systems and create cross-functional documents ensures (1) emergency power (internal or from electrical systems) keeps critical BMS functions operating, (2) the smoke control panel for the local fire department meets their requirements and functions well, (3) power to fans and other devices have the required supervision through the fire alarm and/or BMS, etc.
    - Mechanical rooms HVAC: a common oversight in large buildings is HVAC of mechanical rooms that house many pumps, boilers, chillers, steam and hot-water piping, steam vents, domestic water heaters, and motor controllers that shed heat. It is important that the HVAC engineer compile all these heat loads and provide for cooling the room, so it is a safe and reasonably comfortable space for O&M personnel to work there.
    - Access to HVAC equipment: equipment may require catwalk systems in enclosed spaces that require integration between HVAC, architectural, owner O&M, and structural design team members so that equipment can be safely and easily accessed for routine maintenance and repair.
    - Plenums: it is critical to know exactly how much open area is available for air movement through plenums. This means integrating their design with every other discipline working in the same space (e.g., plumbing pipes, structural steel, electrical conduit, communications cables, ceiling grids). An air plenum though a 3 ft tall space between a ceiling and the deck above can go away when a 30 in. beam reduces it to 6 in., and every other trade is trying to get through the restricted, leaving inadequate (or no) open area for air movement.
    - Controls: to ensure that the building will be operated in accordance with design intent, the owner, design team, and project integrator must understand and plan for good off-site monitoring capability of building control systems by the design team, contractors, and project integrator (as applicable) before and after the building has been turned over to the occupants.
- Be a present and active contributor to the entire design process, providing opinions of how systems will be affected by all project decisions, influencing other design professionals to make their systems decisions and designs integrate well for the good of the whole-building performance.
- Ensure that changes to the OPR or BOD are well understood by the entire team, documented, and made with conscious awareness by all involved.
- Work with the commissioning agent to ensure that the test procedures and performance acceptance limits defined in the commissioning protocols and OPR represent what can be expected from the systems designed. If not, work with the team to align these documents.
- Provide guidance and opinions about team decisions in which members have experience, even if it is outside their specialty.

**Integration Leader.**

- Setting meeting agendas

- Facilitating cross-functional teamwork of the project, beginning with initial team organization
- Facilitating conflict resolution discussions and documenting outcomes
- Ensuring that all decision making is focused on building performance to meet the OPR and BOD
- Ensuring that decisions to alter the OPR or BOD are well documented, made by the team with full knowledge, and agreed to by the owner
- Keeping records of decisions made and follow-up work required

### Performance Requirements

This phase produces the design for the entire building, so the work affects all aspects of building performance. The goal is to meet the performance requirements set in phase 3.

Where there is an opportunity to upgrade performance requirements, document the opportunity along with the newly proposed and accepted requirement

If a performance condition must be downgraded, identify the cause and the mitigating measures to be deployed in different systems or locations that will maintain the whole-building performance level.

### Tools

- Typical architecture and engineering design and calculation systems
- Building performance modeling systems
- Life-cycle analysis tools
- Construction cost estimating
- Three-dimensional CAD systems
- BIM systems

### Documentation

- Complete set of schematic design drawings
- Complete set of developed design drawings suitable for pricing, including
  - Plans, sections, elevations, details, system schematics, riser diagrams, etc.
  - Diagrams, tables, and schedules
  - Performance requirements for all spaces and systems, including measurements techniques for proving acceptable performance (final OPR)
  - Commissioning tests to be performed and contractors’ responsibility to perform the tests and achieve acceptable performance
  - Updated BOD
- Updated financial justification documents required by the owner to support new or expanded financing for the project
- Plan to complete phase 5, including key team members, objectives, funding required, and schedule

## 2.6 PHASE 5: CONSTRUCTION PREPARATION

Phase 5 produces the needed agreements between contractor(s) and owner, authorizing contractors to begin construction. It also produces the construction permit documents.

For an IBD project, this process is usually the same as with a conventional design-bid-build approach. The prime consultant assembles the pricing documents and releases them to contractors. Over the pricing period, the designers provide clarifications of intent based on questions from the contractors and decide the acceptability of alternatives proposed by the contractors. Once the proposals are received from contractors, the design team assists the owner with evaluating proposals and negotiations, leading to the signing of a construction contract.

For IPD projects, rather than a hand-off from designer to constructor, there is simply a shift of team activity from design to construction. The design team reduces its input to a supporting role for the construction team. Conversely, the principal contractors mobilize their forces to implement the work as described in the "issued for construction" documents.

The OPR becomes part of the commissioning protocols and is issued as part of the contract documents, along with the BOD, to define acceptable performance and design intent. Construction scope of work includes achievement of acceptable building performance. Therefore, the OPR and BOD may be distributed to subcontractors by the general contractor (GC) or construction maintenance (CM) contractor as needed.

## Purpose

- Agreement between the owner and prime contractor on the scope and price of construction and execution of construction contracts between them and those between the prime contractor and the mechanical and electrical contractors
- Obtaining building permit(s) necessary to start work
- Integration of new members into the project team and establishing the means, methods, lines of communication, and authority they will work within to decide changes during construction

## Prerequisites

- Design documents have been issued and are suitable to secure bids and negotiate pricing.
- Funding is approved for phases 5 and 6, so that construction contracts may be executed.

## Team

- General contractor or construction manager
- Major subcontractors (structural, mechanical, electrical)
- Integration specialist
- Empowered owner employees authorized and qualified to make decisions immediately as required by designers
- Design professionals: facility programming specialist, architect, civil engineer, mechanical engineer, electrical engineer, energy analyst/modeler
- Commissioning agent
- Specialty contractors: prefabricators, facade specialists, renewable energy designers and installers, testing labs, building performance test contractors, controls specialists, building automation specialists

If the project is to be limited to IBD, then the constructors would be excluded from the team.

## Work

If the project has been proceeding as an IBD project,

- Identify prospective contractors and ask them to bid.
- Prepare bid instructions and send bid requests.
- Answer questions raised by bidders.
- Confirm constructability and methods with GC/CM and lead trades.
- Decide whether bid qualifications are acceptable, particularly where they may affect performance relative to the OPR or systems concepts relative to the BOD.
- Examine bids and select contractors.

- If necessary based on bid prices, revise the design, OPR, and BOD to reduce cost of construction by reiterating the steps in phase 4.
- Negotiate, prepare, and execute construction contract(s).
- Produce construction contract documents plans, specifications, and commissioning protocols:
  - Reflect answers to bid questions.
  - Reflect agreed changes from bid qualifications.
  - Issue construction documents for permitting and contract reference.

If the project has been proceeding as an IPD project, the main contractors have already been selected and have been part of the design team. Cost estimates were complete in phase 4. The business agreement(s) for construction was drafted in phase 2, awaiting the agreed upon price for completion and execution. The plans and specifications issued at the end of phase 4 are the contract documents. Phase 5 requires that

- The owner and contractor(s) finish and execute the construction contract.
- The design team makes any changes needed so that the phase 4 plans and specifications are acceptable to the building officials during permit review.

Prepare a plan to complete phase 6, including key team members, objectives, funding required, and schedule:

- Update the team charter prepared in phase 3 documenting the project priorities in support of the OPR, revising the protocols for decision making so they are appropriate to the construction phase.
- Update the means and methods for project communication and decision making that will continue the cross-functional team decision making focused on meeting the OPR.
- Prepare the construction schedule.
- Update the budget, including agreed cost of construction or its limits.

## Sequence of Events

If it is an IBD project, manage the bid process and finalize the construction/contract documents; if it is an IPD project, make any changes to the phase-4 plans and specifications needed to meet the project’s purpose, issue the construction/contract documents, and finalize the construction contract(s).

## Team Roles

**Design Team Member.**

- Answer questions that may arise from the bid process and amend plans and specifications as warranted.
- Be a present and active contributor to discussions about bid questions, bid qualifications, and design changes that may be required, and provide opinions of how systems will be affected by these decisions.
- Ensure that changes to the OPR or BOD are well understood by the entire team and made with conscious awareness by all involved.
- Provide guidance and opinions about experience members may have with bidding contractors, even if it is outside their specialty.
- Complete the design elements for which they are responsible, in coordination with other design disciplines and with the assistance of trades.

**Integration Leader.**

- Facilitating cross-functional teamwork of the project, which now ensures changes proposed during construction are decided with the same rigor and transparency as those made during design
- Revising the team charter to reflect that the principal activity is now construction and that priorities in communications may change

- Facilitating sound decision making focused on building performance, although overall project management now moves to the general contractor
- Ensuring that all decision making is focused on building performance to meet the OPR, that decisions to alter the OPR or BOD are made by the team with full knowledge and agreement by the owner, and that such decisions are well documented
- Keeping records of decisions made and follow-up work required

### Performance Requirements

This phase may change the design for the key building systems. Therefore, the work affects all aspects of building performance. The goal is to meet the performance requirements set in phase 3.

Where there is an opportunity to upgrade performance requirements, document the opportunity along with the newly proposed and accepted requirement.

If a performance condition must be downgraded, identify the cause, and identify the mitigating measures to be deployed in different systems or locations that will maintain the whole building performance level.

### Tools

- Typical architecture and engineering design and calculation systems
- Building performance modeling systems
- Life-cycle analysis tools
- Construction cost estimating
- Three-dimensional CAD systems
- BIM systems
- Project management and scheduling systems
- Data recording and tracking tools

### Documentation

- Complete “issued for construction” plans, specifications, and commissioning protocols
- Updated team charter
- Executed construction contracts (minimum would include general, mechanical and electrical contractors)
- Meeting records and logs of all agreements reached that are a basis for the final contract
- Plan for phase 6, including the key team members, objectives, funding required, and schedule

## 2.7 PHASE 6: CONSTRUCTION

Phase 6 is the construction of the building, followed by startup, testing, and debugging of all systems, verifying that they perform as required by the contract documents and local authorities.

The main work of this phase is to build the building and its systems as defined by the contract documents. This work is done by the contractors. The rest of the team provides support and oversight to ensure that the building is built according to the design and that decisions made during construction will lead to systems performing as required by the OPR.

Near the end of phase 6, systems will be shown to operate well enough for the owner to safely use the building, which occurs in phase 7.

### Purpose

- Construct the building.

- Get systems operating well enough to make the building safe and reasonably comfortable for occupancy.
- Secure permission from the authorities having jurisdiction (AHJs) to occupy the building.

## Prerequisites

- Drawings, specifications and commissioning plans are approved, and permits have been issued to begin construction.
- The project price is agreed between the owner and contractor(s).
- Contracts between the owner and main contractors have been executed.
- Means and methods for project team communication and decision making are clearly defined.
- The construction documents include answers to all bid questions and scope of work change agreements.
- The construction documents include all cost reduction design changes and related OPR changes.
- The team agrees that commissioning work completed in accordance with construction documents will prove that building performance meets the OPR.
- The contractors are prepared to perform the commissioning tests and inspections required by construction documents.
- The plan to complete phase 6, including key team members, objectives, funding required, and schedule, is complete and approved by the owner.

## Team

- General contractor or construction manager
- Major subcontractors (structural, mechanical, electrical)
- Integration specialist
- Owner’s facility management/maintenance staff
- Design professionals: facility programming specialist, architect, civil engineer, mechanical engineer, electrical engineer, energy analyst/modeler
- Commissioning agent
- Specialty contractors: prefabricators, facade specialists, renewable energy designers and installers, testing labs, building performance test contractors, controls specialists, building automation specialists

## Work

The work is described as it would occur in an IPD project where the contractors were part of the integrated cross-functional team before or, at latest, during design. During construction, the difference between an IBD and an IPD project is that, in an IPD, the general and specialty contractors have participated in the design and thus have eliminated potential conflicts between systems and other constructability challenges. Although unanticipated site conditions may still cause difficulty for IPD projects, it is expected that activities documented in the design drawings will be relatively conflict and delay free.

The work of this phase is to build the building and its systems as defined by the contract documents. This work is done by the contractors. The rest of the team provides support and oversight to ensure that the building is built according to the design and that decisions made during construction will lead to systems performing as required by the OPR.

The owner, designers, and commissioning agent perform the following work throughout construction:

- As shop drawings are prepared, new subcontractors are hired and materials and equipment are purchased; the team must consider the effect that any proposed changes will have on building performance. The team ensures that changes proposed are approved or rejected with the same rigor and transparency as during design. Should proposed changes enhance or diminish building performance, the OPR and the projected project cost must be revised and accepted by the owner.

- During construction, there are inevitable imperfections in the design and unanticipated construction obstacles that must be overcome. The integrated team now works together to facilitate construction and to solve problems in ways that do not diminish the building's performance relative to the OPR.
- They make routine visits to the job and observe the work, reporting what is and is not being done in accordance with plans and specifications.
- As systems are installed, the process of start-up, testing, and debugging occurs. This work is done by the contractors and the commissioning agent. The goal of this work is usually to get systems working well under the weather conditions of the time and without normal owner use and occupancy. This part of commissioning may show that acceptable performance cannot be achieved because construction did not adhere to designs or designs do not perform as intended. In these cases, the team works together to solve the problems and either achieve required performance or agree that the performance is insignificantly deficient and acceptable as is.
- Near the end of this phase, the AHJs inspect work and supervise tests of systems, particularly life safety systems. As with commissioning tests, if performance is not acceptable to the AHJs, then the team works together to solve the problems and achieve required performance.

## Sequence of Events

1. Main contractors begin procurement of subcontractors, materials, and equipment, resulting in submittals review by the rest of the project team.
2. Contractors begin construction and proceed through the stages of
    a. Site work, civil, and utility services construction
    b. Foundations
    c. Superstructure and infill for floors, roofs, and walls
    d. Exterior assemblies, including fenestration
    e. Building services: plumbing and fire protection, ventilation, heating and cooling, electrical power systems, lighting systems, and controls and communications
    f. Finishes and fit-up
3. Whole team resolves problems that arise during construction and ensures that resolutions do not diminish building performance

## Team Roles

**Design Team Member.**

- Review shop drawings and submittals for materials and equipment. Ensure that what the contractors plan to do is in agreement with the intent of the design documents. Inform the rest of the team if information shows that the work of other disciplines may be affected by departures from the design, and ensure that the entire team reviews the situation and agrees on what the contractor will be required to do. Ensure that any substitution of equipment or material will not diminish building performance without prior acceptance by the owner.
- Routinely visit the project, observe the work, and report observations. If the work does not adhere to the contract documents, then bring the situation to the attention of the entire team, and agree on its resolution to ensure the performance of all systems will be acceptable.
- Be a present and active contributor to discussions of construction work and situations that may require design changes, whether to HVAC systems or others. Provide opinions of how systems will be affected by changes to other systems. For example, a seemingly simple wall move may require a significant change to an HVAC system.
- Support the start-up, test, and debug work to help contractors and the commissioning agent efficiently bring systems to successful operation. Lead the effort to make design changes if needed so that the whole team can make integrated supporting changes.
- Answer questions (requests for information [RFIs]) promptly to keep construction progressing on schedule. Bring questions that may affect other systems to the attention of the whole team for answers.

- Ensure that changes to the OPR or BOD are well understood by the entire team and made with conscious awareness by all involved.

**Integration Leader.**

- Facilitating the cross-functional teamwork of the project, which now requires ensuring that changes proposed as construction progresses are decided with the same rigor and transparency as those proposed during design
- Supporting contractors by facilitating the cross-functional resolution of field problems efficiently and quickly; bringing everyone affected by a situation (contractors, designers, commissioning, and owner employees) together as needed to make integrated decisions
- Ensuring that all decision making is focused on the building performance to meet the OPR and that decisions to alter the OPR are made by the team with full knowledge and agreement by the owner and are well documented
- Keeping records of decisions made and follow-up work required

### Performance Requirements

This phase may require changes to the design for the key systems of the building. Therefore, the work affects all aspects of building performance. The goal is to meet the performance requirements set in phase 3.

Where there is an opportunity to upgrade performance requirements, document the opportunity along with the newly proposed and accepted requirement.

If a performance condition must be downgraded, identify the cause, and identify the mitigating measures to be deployed in different systems or locations that will maintain the whole building performance level.

### Tools

- Typical architecture and engineering design and calculation systems
- Building performance modeling systems
- Life-cycle analysis tools
- Construction cost estimating
- Three-dimensional CAD systems
- BIM systems
- Project management and scheduling systems
- Data recording and tracking tools

### Documentation

- Review of comments on shop drawings and submittals
- Design for revision drawings and specifications
- Site instructions, contemplated change notices, and change orders
- Formal questions and answers (RFIs) between contractors and designers
- Records of all decisions made by the team
- Updates to the OPR, if needed

## 2.8 PHASE 7: OWNER ACCEPTANCE

Final commissioning (monitoring and tuning of systems) begins after the owner occupies the building and it begins to perform under its intended conditions.

Phase 7 accomplishes the hand-off from the contractors to the owner. Formal acceptance of the building by the owner happens in accordance with the construction contracts. During this phase, the owner or occupants begin using the building. The owner’s facility management/maintenance staff is provided with the documentation and training they will need to successfully operate and maintain the building so that it performs in accordance with the OPR throughout its life. The owner accepts responsibility to occupy, operate, and maintain the building. The project team remains responsible for proving that the building performs as required by the OPR.

## Purpose

- Prepare the owner's facility management/maintenance staff to operate and maintain the building properly.
- Have the owner occupy the building and begin its intended use, thus beginning the period during which the building is proven to operate as intended during normal operating conditions.

## Prerequisites

- Construction is complete in accordance with the construction documents and certified as such in accordance with the commissioning requirements.
- Owner's facility management/maintenance staff members were present during construction and agree that systems are maintainable.
- All systems are operating as intended and certified as such in accordance with the commissioning requirements.
- The AHJs have performed all their necessary inspections and tests and have approved the building for occupancy.
- Owner's facility management/maintenance staff members agree that they have been trained to properly operate and maintain all building systems.
- Plan for phase 7 is complete, including key team members, objectives, funding required, and schedule.

## Team

- General contractor or construction manager
- Major subcontractors (structural, mechanical, electrical)
- Integration specialist
- Owner's facility management/maintenance staff
- Design professionals: facility programming specialist, architect, civil engineer, mechanical engineer, electrical engineer, energy analyst/modeler
- Commissioning agent
- Specialty contractors: prefabricators, facade specialists, renewable energy designers and installers, testing labs, building performance test contractors, controls specialists, building automation specialists

## Work

- Support the owner during move-in, when they integrate their own equipment into the building systems.
- Organize and carry out owner training programs. The training team includes
    - System designers
    - Commissioning agent
    - Installing contractors
    - Equipment manufacturers
- Produce operation and maintenance documents, including
    - "As built" plans and specifications
    - Up-to-date OPR

  - Training manuals
  - Equipment owner's manuals
  - Maintenance procedures
- Set up performance monitoring systems in the BMS, including alarm limits that reflect the acceptable performance ranges set in the OPR.
- Ensure off-site monitoring capability of building control systems is functioning and adequate.

## Sequence of Events

1. Owner move-in
2. Owner training coincident with delivery of documentation
3. Establishment of maintenance procedures and incorporation into the owner's maintenance management system
4. Setup of performance monitoring systems for long-term use by the owner and final-phase commissioning work

## Team Roles

**Design Team Member.**

- Be a present and active contributor to training the owner about the systems and how they interact and are integrated with other systems in the building. When training is done, ensure that the owner understands the performance requirements documented in the OPR and the monitoring systems that detect departures from acceptable performance so repairs can be made to return to desired performance.
- Work with the rest of the team to produce the documentation that the owner needs to operate and maintain the building. This includes the final OPR, as-built plans and specifications, equipment manuals, controls system programming, resource contact information, etc.

**Integration Leader.**

- Facilitating the cross-functional teamwork of the project, particularly the training sessions, to ensure that they are effective and that the owner's staff actively engages in the process
- Completing the final update of the OPR and delivering to owner
- Keeping records of decisions made and follow up work required

## Performance Requirements

This is the knowledge transfer phase, during which the owner prepares to operate and maintain the building. Therefore, the work affects all aspects of building performance. The goal is to educate the owner and set up their maintenance systems to meet the performance requirements, set in phase 3, throughout the life of the systems.

## Tools

- Typical architecture and engineering design and calculation systems
- Building performance monitoring systems (energy and indoor environment quality data)
- Three-dimensional CAD systems
- Visual presentation tools
- Technical writing skills
- BIM systems
- Computerized maintenance management systems (CMMS)

- Data recording and tracking tools
- Capital asset tagging and tracking system

### Documentation

- Complete as-built plans and specifications
- Equipment owner's manuals
- Manufacturers' training materials
- Preventive maintenance procedures installed in the owner's maintenance management system

## 2.9 PHASE 8: USE, OPERATION, AND MAINTENANCE

Phase 8 spans the warranty period of the building, usually one year. During this time, the commissioning agent and owner's facility management/maintenance staff monitor performance of all building systems to ensure that they operate as intended during normal operating conditions and through all seasons. The commissioning agent leads the work to tune systems for proper performance, if needed, and relies on other team members (contractors and designers) as needed to achieve satisfactory systems performance, particularly as systems respond to changing conditions.

### Purpose

- Ensure that operating performance under normal use and occupancy meets the OPR.
- Confirm that O&M personnel are in place and prepared for ongoing operation to maintain building performance in accordance with the OPR.
- Complete the project, as agreed by all team members.

### Prerequisites

- All systems are operating and performing in accordance with the OPR but have not yet performed under intended conditions.
- The owner has the complete documentation needed for operation, maintenance, and repair of the building from contractors and designers.
- All required documents and maintenance procedures are incorporated into the owner's maintenance management system.
- The owner's O&M people are trained in the proper operation and maintenance of the integrated whole-building systems.
- The owner is prepared to operate and maintain building performance in accordance with the OPR.
- The team's plan to monitor performance during the warranty period, tuning and repairing systems as necessary to achieve performance in accordance with the OPR, is complete.

### Team

- General contractor or construction manager
- Major subcontractors (structural, mechanical, electrical)
- Integration specialist
- Owner's facility management/maintenance staff
- Design professionals: facility programming specialist, architect, civil engineer, mechanical engineer, electrical engineer, energy analyst/modeler
- Commissioning agent

- Specialty contractors: prefabricators, facade specialists, renewable energy designers and installers, testing labs, building performance test contractors, controls specialists, building automation specialists

## Work

At this stage, all systems are operating and performing in accordance with the OPR, but have not yet performed under intended conditions. The commissioning team monitors performance of all systems relative to the performance requirements set in OPR. Systems that do not meet the performance requirements will be tuned, reworked, and, in the worst case, redesigned and replaced as necessary to achieve acceptable performance.

If redesign is necessary, the work will be as described in previous design and construction phases.

Contractors continue work to complete minor deficiencies observed during construction and since owner move-in.

The owner's facility management/maintenance staff participate in identifying unacceptable performance, tuning systems, and troubleshooting alongside the commissioning agent and installing contractors. This effort is part of the owner's training for long-term building operation and maintenance.

The project team works together at the end to ensure that everyone is satisfied that the building as built is performing in accordance with the OPR.

## Sequence of Events

- Monitor performance of all systems.
- Take required action to make all systems perform in accordance with the OPR.
- Work with the owner's facility management/maintenance staff to ensure that they are prepared to keep all systems operating as intended.
- Reach consensus across the entire team that the project is complete with all systems performing as intended.

## Team Roles

**Design Team Member.**

Visit the project, observe the work, and close out open deficiencies noted in field reports as contractors' complete corrective work.

Support tuning and troubleshooting work to help the owner, contractors, and commissioning agent efficiently bring the systems to successful operation. Lead the effort to make design changes if needed, so that the whole team is able to make integrated supporting changes.

**Integration Leader.**

- Facilitate cross-functional teamwork of the project, particularly if redesigns are needed to achieve acceptable performance.
- Ensure that all decision making is focused on building performance to meet the OPR and that decisions to alter the OPR are made by the team with full knowledge and agreement by the owner and are well documented.
- Facilitate the final team meetings to reach consensus about work remaining to complete the project, and ultimately to agree that the project is finished.
- Keep records of decisions made and follow-up work required.

## Performance Requirements

This phase may require changes to the design for the key systems of the building. Therefore, the work affects all aspects of building performance. The goal is to meet the performance requirements set in phase 3.

If a performance condition must be downgraded, identify the cause, and identify the mitigating measures to be deployed in different systems or locations to maintain the whole building performance level.

## Tools

- Performance monitoring and data collection systems and devices
- Data analysis tools, such as statistical problem solving

- Troubleshooting tools and skills
- Building performance modeling systems
- Life-cycle analysis tools

### Documentation

- Commissioning report
- Documents from team members (in accordance with contracts and AHJ requirements) attesting that the project is complete and performing as intended

## 3. TERMINOLOGY

Italicized terms in definitions are defined elsewhere in this section.

**BOD.** Basis of design

**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 is prepared and submitted to the client with the fee proposal. 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 (CM), who is responsible for project delivery 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 work hand in hand throughout the iterative evaluation process.

**Building information modeling (BIM).** Building information modeling extends the initial position of *three-dimensional CAD* to an object-based approach, documenting information about building elements in a master database of construction information. Information recorded about each building object can go beyond physical dimensions to include performance properties such as structural strength or thermal conductivity, its installation scheduling, service life, capital cost, maintenance requirements, or any other description of a delivered service. Development of a BIM model is essentially constructing the building in a virtual environment. All BIM objects are located in three dimensions referenced to a common origin, which makes services like clash detection automatic. The origin can be geolocated, allowing the BIM model to communicate with and incorporate survey data or other geolocated object descriptions.

Initially, a hope for BIM was that all disciplines could work from a common reference database, enabling everyone to work with the most updated information. However, having everyone work from a common platform requires all disciplines to work with the same software and version, requiring coordination of software updates. This is not feasible in many cases, resulting in the more common experience of each discipline developing its information independently and requiring a coordinated reintegration to achieve a complete model. Regardless of the complexities of this approach, BIM platforms deliver faster and more accurate documentation than simple CAD methods.

**Charter of values.** A charter is a document that establishes the rules of engagement, obligations and benefits, or relationships between members of an organization. For a building design effort, a project charter, building design charter, or similarly named document of agreements, augments the *OPR* by establishing hierarchies of importance for the many possible solutions to design requirements. A hierarchy of importance is necessary for the charter to be useful in guiding choices between competing potentials in project development. For example, with regard to the energy efficiency of a project, the OPR may specify a required energy use intensity for the finished building, but the charter may, based on attitudes presented in the OPR, establish a hierarchy that prioritizes investment in the building enclosure over investments in heating or cooling equipment efficiencies.

**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 realizes designer intent and owner expectations.

ASHRAE *Guideline* 0 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."

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 post-acceptance 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
- Reviews the design to ensure the HVAC project accommodates the commissioning process
- Coordinates with the owner, design engineer, and HVAC contractor
- 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 intensive process that should be used when integrated-system-based design solutions are provided. See Chapter 44 for more information.

**Compensation models.** How firms get paid for their work differs between SPD, *IPD*, and *IBD* projects. The standard for sequential and IBD projects is design-bid-build. IPD usually uses some form of cost + fee with guaranteed maximum price (GMP). There are variations on both of these compensation models.

Those leading the field of IPD have developed models that ensure all contributors to the project (including the design team) are compensated for only their cost as the project progresses, then share the profits, which increase if they work effectively together, when the project is done. For businesses or government agencies that have no choice but to use design-bid-build, they must be creative with defining these three areas of work if they want to use IPD.

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 that represent inclusive elements of the project.

**Constructability.** This term describes the efficacy with which a facility can be built. A project that is deemed "easily constructable" has fewer risks of schedule delays and change orders arising from poor coordination or confusion over construction sequencing.

At project outset, constructability is measured by 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. In *IBD* projects, a constructability review is an additional activity, wherein knowledgeable construction representatives provide objective feedback on the constructability of developing system solutions. In *IPD* projects, the construction representatives are part of the design team and contribute their knowledge of constructability as the documents are being prepared.

**Critical operations.** Some design objectives are critical to the future operation of particular facilities (e.g., data centers, emergency response, law enforcement, government, health care, shelters, manufacturing, pharmaceutical facilities). For example,

- Designers of facilities that require high **reliability** must focus on ensuring that systems and components meet the specified probability that they will operate for the duration of use. As the required reliability increases, infrastructure design must respond in kind with system redundancy and diversity.
- Designers of 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.

**Drawings.** 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 to one another of the elements of construction 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.

**Energy modeling.** Energy modeling uses scientific methods and analytical tools to estimate 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) EnergyPlus or DOE-2/eQUEST. Commercial products are also 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 creating 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 of the 2021 *ASHRAE Handbook—Fundamentals* for an in-depth discussion of modeling methods for systems design and design optimization.

**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 (energy use intensity [EUI] site).
- Provide a facility source energy density of less than owner-defined consumption per unit area (EUI source).
- 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 points becomes the primary focus. See also Chapter 37.

**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.

**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 **repurposing** (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.

**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. See Chapter 49 of this volume, and Chapter 8 of the 2021 *ASHRAE Handbook—Fundamentals*.

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. See Chapter 9 of the 2021 *ASHRAE Handbook—Fundamentals*.

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. See Chapter 64 of this volume, and Chapter 37 of the 2021 *ASHRAE Handbook—Fundamentals*.

**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 effectiveness $E_z$ ranging from 0.5 to 1.2 for various air distribution configurations. A possible objective 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.

**Integrated building design (IBD) and integrated project delivery (IPD).** IBD integrates only the activities of design professionals. IPD extends integration to include constructors in the design process and follow-through. Thus, the team addresses issues of constructability, scheduling, and cost control during design so that construction can be more efficient. These skills may reduce project capital cost and/or improve delivery schedules. Accessing the skills of the constructor does involve a trade-off: a shift from using a price based on completed design documents, prepared in the absence of input from builders, to the cost of a project being established by a sequence of price definitions, developed as the project design matures.

IPD offers increased flexibility in directing scope to match a desired cost. This mitigates the risk of making a contractual connection to construction expertise before a project is "finished" in a design sense. It also enhances the initial benefits offered by the integration of design professionals through access to additional knowledge.

Both approaches emphasize 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 IPD 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 to the completion of construction, commissioning, handover and startup, and operations and facility management.

**Life-cycle cost analysis tools.** All system evaluations share a common need to demonstrate the financial effects 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 (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 (energy.gov/eere/femp/). Chapter 38 contains more information on LCCA.

**Operational review.** Operational reviews should be conducted during design development and construction document phases. 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

- The appropriate level of system and component commissioning has been prescribed.
- Adequate and usable closeout documentation has been itemized.
- 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, so 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.

**OPR.** Owner's project requirements.

**Programming.** When new facility space is required, the owner must first evaluate available options. These include build new, modify existing, or relocate. Scenarios should be debated to determine which option provides the best fit alternative.

**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, and current records of the facts discussed and decisions made (and by whom) in meetings, during site visits, in emails, 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.

**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* (Construction Specifications Institute).

*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.

**Three-dimensional CAD.** Three-dimensional CAD (computer-aided drafting) uses graphical computer interfaces to create representations of buildings or building elements that can be viewed in three dimensions. This technique supports coordination efforts between design disciplines to identify spatial conflicts between building systems. Three-dimensional CAD systems do not necessarily automate tasks such as clash detection, and may require human intervention to deliver those services.

**Value engineering.** Value engineering is commonly an exercise undertaken when the project appears to be over budget and costs must be reduced. In the worst cases, costs are reduced from the most expensive items in a line item budget without reference to the *OPR* or performance requirements. Value engineering in *IBD* and *IPD* projects is most successfully used in the evaluation of concept options in phase 3 and the ongoing evaluation of detailed design solutions in phase 4. No final method, assembly, or system should be accepted as part of the BOD without performance and financial analysis. In this way, value is maintained and the misuse of "value engineering" avoided.

**Vulnerability (hazard containment and protection).** 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 61 for more information.

**Water usage.** *IPD* objectives for water usage typically focus on conservation and reclamation efforts. Water has a cost associated with its use, and should be included when modeling 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 with a HVAC influence include the following:

- Reclaim all cooling condensate discharge for use in graywater systems. Note that reclaimed graywater can be used in 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 graywater 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, or microbial growth.

# REFERENCES

ASHRAE members can access *ASHRAE Journal* articles and ASHRAE research project final reports at technologyportal.ashrae.org. Articles and reports are also available for purchase by nonmembers in the online ASHRAE Bookstore at www.ashrae.org/bookstore.

ASHRAE. 2020. Thermal environmental conditions for human occupancy. ANSI/ASHRAE *Standard* 55-2020.

ASHRAE. 2022. Ventilation for acceptable indoor air quality. ANSI/ASHRAE *Standard* 62.1-2022.

ASHRAE. 2022. Energy standard for buildings except low-rise residential buildings. ANSI/ASHRAE *Standard* 90.1-2022.

ASHRAE. 2013. The commissioning process. ASHRAE *Guideline* 0.

buildingSMART®. 2014. *Building SMART®: International home of open BIM®*. www.buildingsmart.com.

CSI. 2018. *MasterFormat*. Construction Specification Institute, Alexandria, VA. www.masterformat.com.

ISO/PAS. 2013. Industry foundation classes (IFC) for data sharing in the construction and facility management industries. *Standard* 16739. International Organization for Standardization, Geneva.

NIST. 1996. *Life-cycle costing manual for the Federal Energy Management Program*, 1995 ed. *Handbook* 135, S.K. Fuller and S.R. Petersen, eds. National Institute of Standards and Technology, Gaithersburg, MD, and U.S. Department of Energy, Washington, D.C. fire.nist.gov/bfrlpubs/build96/art121.html.

# BIBLIOGRAPHY

ASHRAE. 2007. HVAC&R technical requirements for the commissioning process. *Guideline* 1.1-2007.

ASHRAE. 2011. *Advanced energy design guide for small to medium office buildings*. ASHRAE Special Project SP-133. ASHRAE.

ASHRAE. 2013. *ASHRAE greenguide: Design, construction, and operation of sustainable buildings*, 4th ed.

AIA. 2001. *Architect's handbook of professional practice*, 13th ed. John Wiley & Sons, New York.

AIA. 1997. Standard form of agreement between owner and architect. *Document* B141-1997. American Institute of Architects, Washington, D.C.

AIA. 1995. Project checklist. *Document* D200-1995. American Institute of Architects, Washington, D.C.

CCDC. 2010. Construction management contract—for services. *Document* CCDC 5A–2010.

CCDC. 2010. Construction management contract—for services and construction *Document* CCDC 5B–2010.

CII. 2006. *Constructability implementation guide*, 2nd ed. SP34-1. Construction Industry Institute, Austin.

Clark, K.B., and T. Fujimoto. 1991. *Product development performance—Strategy, organization, and management in the world auto industry*. Harvard Business School. Boston, MA.

CSI. 2005. *Project resource manual*, 5th ed. Construction Specification Institute, Alexandria, VA.

EJCDC. 2002. *Standard form of agreement between owner and engineer for professional services (E-500)*. Engineers Joint Contract Document Committee, National Society of Professional Engineers, Alexandria, VA.

Holness, G.V.R. 2006. Building information modeling: Future direction of the design and construction industry. *ASHRAE Journal* 48(8):38-46.

ISO. 2004. Industrial automation and systems integration—Product data representation and exchange—Part 11: Description methods: The EXPRESS language reference manual. *Standard* 10303-11. International Organization for Standardization, Geneva.

Lewis, M. 2004. Integrated for sustainable buildings. *ASHRAE Journal* 46(9): S22-S30

NIBS. 2007. *National BIM standard—United States™ version 2*, annex B: *National BIM standard—United States™ version 1—Part 1: Overviews, principles, and methodologies.* National Institute of Building Sciences, Washington, D.C.

PECI. 2006. *Model commissioning plans and guide specifications online*, v2.05. Portland Energy Conservation, Inc., OR. www.peci.org/large-commercial/mcpgs.html.

PDMA. 1996. *The PDMA handbook of new product development*. John Wiley & Sons. New York, New York.

RAIC. 2018. Canadian standard form of contract for architectural services. *Document* Six 2018 ed. Royal Architectural Institute of Canada. www.raic.org/raic/contract-documents.

RAIC. 2005. Canadian standard form of agreement between client and architect (abbreviated version). *Document* Seven 2005 ed. Royal Architectural Institute of Canada. www.raic.org/raic/contract-documents.

RAIC. 2018. Canadian standard form of contract between architect and consultant. *Document* Nine 2018 ed. Royal Architectural Institute of Canada. www.raic.org/raic/contract-documents.

Stoner, J.A.F. 1982. *Management*. Prentice Hall. Englewood Cliffs, NJ.

Salton, Gary J. 1996. *Organizational engineering*. Professional Communications, Inc. Ann Arbor, Michigan.

USGBC. 2006. *Leadership in Energy and Environmental Design online.* U.S. Green Building Council, Washington, D.C. www.usgbc.org.

# RESOURCES

Building Life Cycle Costs (BLCC)
See www.energy.gov/eere/femp/building-life-cycle-cost-programs.

DOE-2/eQUEST
See www.doe2.com/equest.

Energy Plus
See www.energyplus.net.

Energy Star Portfolio Manager
See www.energystar.gov.

LEAN Construction
See www.leanconstruction.org.

Building Owners and Managers Association (BOMA)
See www.boma.org.

Canadian Construction Documents Committee
See www.ccdc.org/.

Hanscomb, Yardsticks for Costing
See www.hanscomb/com/Publications/Yardsticks-for-Costing.

U.S. Energy Information Administration, Commercial Building Energy Consumption Survey (CBECS)
See www.eia.gov/consumption/commercial.

Natural Resources Canada, Comprehensive Energy Use Database (CEUD)
See oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables.

U.S. Environmental Protection Agency, ENERGYSTAR Portfolio Manager
See portfoliomanager.energystar.gov.

R.S.Means Building Construction Cost Data
See www.rmsmeans.com.

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